229

GEOLOGICAL MAGAZINE

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Sir Thomas H. Holland
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Professor C. E. Tilley
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1943

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Vol. LXXX of Whole Series

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GEOLOGICAL MAGAZINE

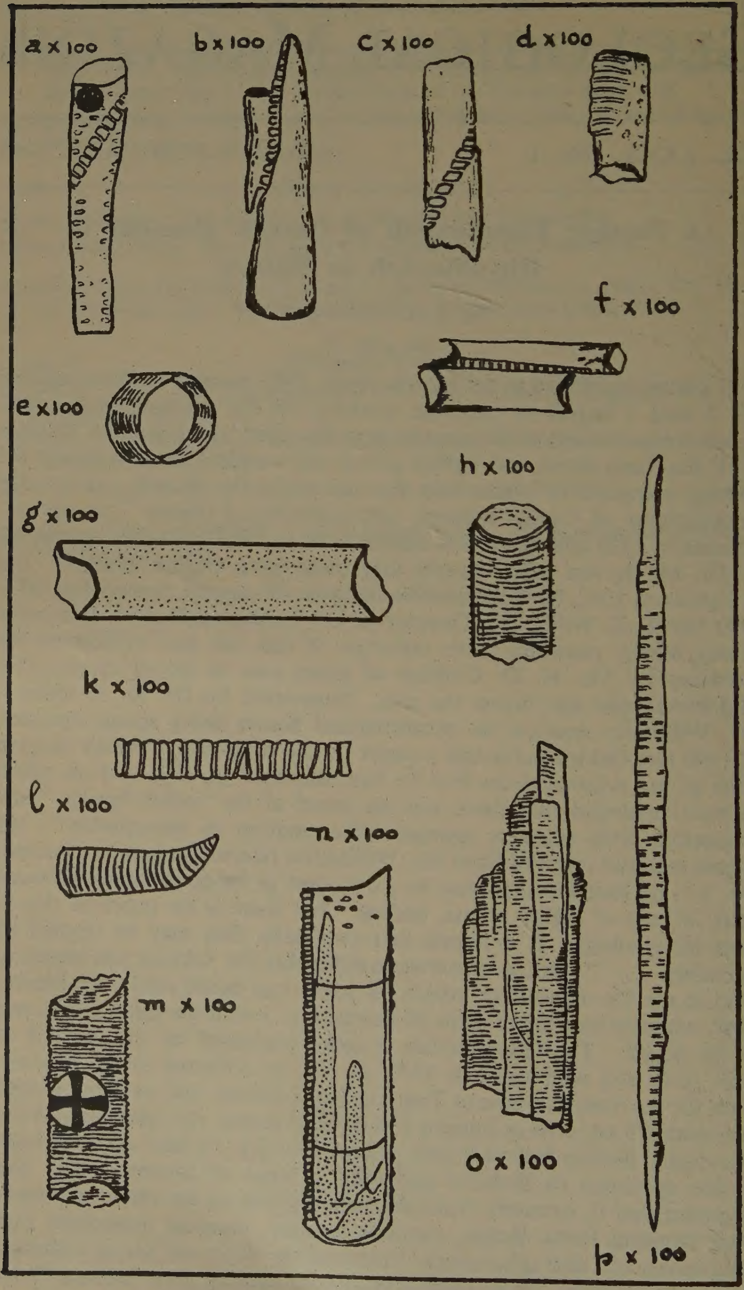
VOL. LXXX. No. 1. JANUARY–FEBRUARY, 1943

A Further Examination of Organic Remains in Rhyolite-Ash in Malaya

By J. B. Scrivenor

(PLATE I)

IN a letter published in the March–April, 1942, number of this magazine I said I hoped to continue working on the problematical bodies found in rhyolite-ash in Malaya and first described by me in 1930. Further work has been done, but before giving the results I must mention the unusual sequence of events that has led up to the present paper. My identification of " rods, spheres, and club-shaped objects " as sponge-remains in 1930 (the work was chiefly done in 1928) was then supported by Dr. M. Burton, who thought they came from marine sponges ; but in February, 1942, he withdrew this support. In *Annual Reports* for 1937–1940 Mr. E. S. Willbourn, Director of the Geological Survey, Federated Malay States, recorded more outcrops of this ash and mentioned the discovery by Mr. H. D. Collings of stone axes in gravel of probably Mid-Pleistocene age below the ash. Supported by Dr. K. P. Oakley, Mr. Willbourn queried the problematical bodies being sponge-spicules. In 1940 Dr. Oakley published a paper in this magazine in which he gave a list of my original slides that he had examined (p. 292) and on which he had concluded that there was no proof of the bodies having " any connection with siliceous sponges either marine or non-marine ", but in new material received from Mr. Willbourn, referred to here as " sample No. 3 ", he found bodies that he recognized as being probably siliceous casts of cells of higher plants, adding " but there is no proof of this in their morphology. It is hoped that eventually they may be studied by botanists. . . ." Owing to war-time difficulties Dr. Oakley was unable to send to me the material on which his paper was based until 30th March, 1942, when he sent the remains of sample No. 3 with the slides mentioned in his paper. The latter include a series registered by me in 1928 as 7729 A–G and mentioned in 1930, p. 387, as collected at the landing-place for the owner's house at Tanjong Perak Estate, and as being judged to contain 75 per cent of pumice and mineral grains, the remaining 25 per cent being diatom-frustules and sponge-spicules. I had no duplicates of this specimen in Bedford and after a lapse of fourteen years had forgotten that it, certainly from the same deposit as the other specimens from Tanjong Perak Estate, contains pointed, tapering monaxons with axial canals and also spherasters. I received the slides too late to withdraw or modify my letter in this magazine without causing great inconvenience to the editors.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TEXT-FIG. 1

I have now examined very thoroughly all the material available during the Japanese occupation of Malaya, and in addition, sand from bath-sponges containing diverse marine sponge-spicules, and also diatom and infusorial earths with freshwater and marine sponge-spicules for comparison. I am greatly indebted to the Linnean Society for allowing me to use their library, particularly the late Professor E. A. Minchin's collection of papers on sponges ; and also to Drs. C. R. Metcalfe and C. L. Hare, of the Jodrell Laboratory, Royal Botanic Gardens, Kew, for examining and discussing with me a number of the microscope preparations, and also for helping me with the text and legends of this paper.

In my 1930 paper there are many microphotographs illustrating this subject. In this paper I can only produce one plate of microphotographs supplemented by inadequate line-drawings by myself, but they will serve to give some idea of the shape and size of the objects under discussion. Colours, where mentioned in the legends, are by transmitted light.

I have avoided as much as possible the Greek words with which the literature on sponges bristles, because I have found that even those better acquainted with that language than I am do not understand all of them without reference to " Liddell and Scott ". Plain English is preferable now that modern languages are so widely studied.

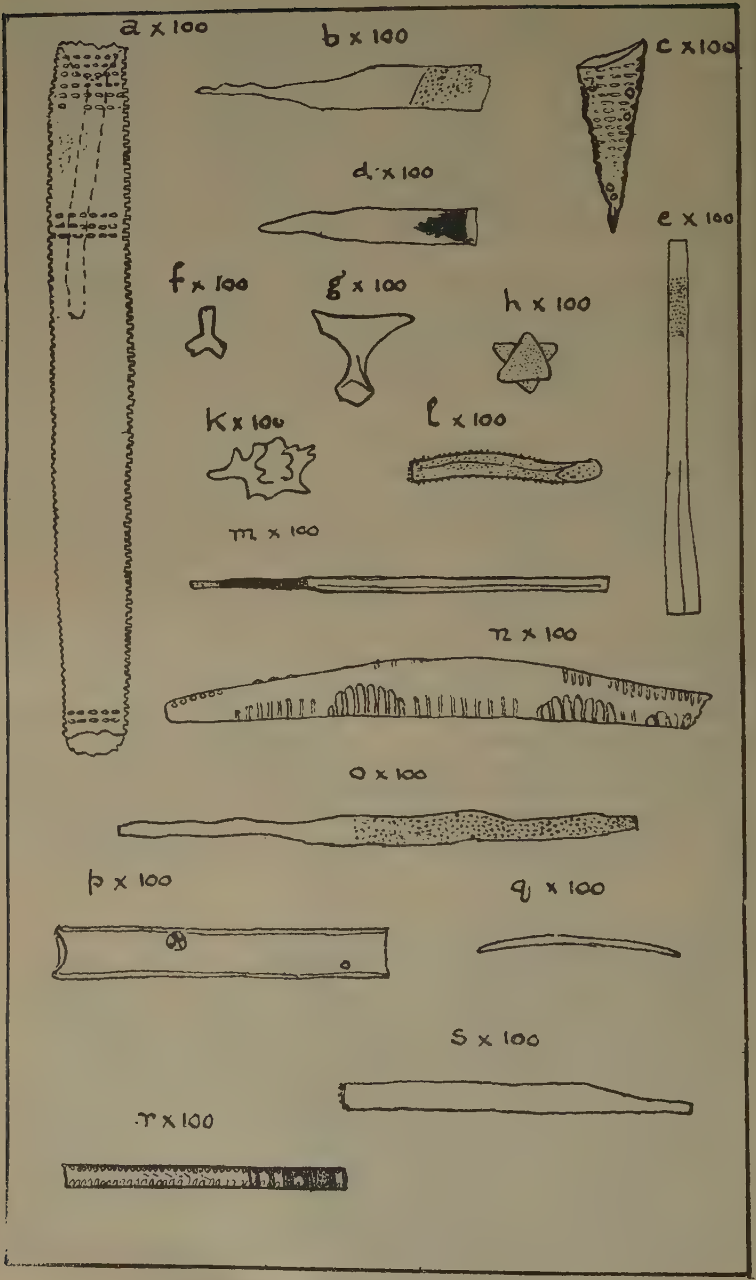
MINERAL CONSTITUTION AND COLOUR

Resistance to *aqua regia* and optical properties point to all the bodies in the ash being silica, and their constant isotropism between crossed nicols suggests opal. This is supported by the opalescent blue colour by reflected light of some of them ; but no chemical analysis on separated material has been possible.

Many of the bodies show circular inclusions with faint double refraction, and in some cases the cross characteristic of spherulitic structure is clearly seen. These inclusions are believed to be the result of alteration of the opal to chalcedony. Similar inclusions are common in sponge-spicules

TEXT-FIG. 1

a. Plant-cells with perforation plate and oval pitting. Colourless.
b. Plant-cells with perforation plate. Colourless.
c. Plant-cells with perforation plate. Colourless.
d. Plant-cell with perforation plate. Colourless.
e. Replacement of part of a plant-cell with scalariform pitting. Colourless.
f. Two plant-cells with pits between them. Colour, brown.
g. Cylinder with granular surface. Colour, brown. Nature, doubtful.
h. Replacement of a plant-cell with scalariform pitting. Brown.
k. A plant-cell with annular pitting ? Colour, yellow. Compare Vines, 1896, p. 104, fig. 58 s, and this paper pl. I, fig. h.
l. Cast of a plant-cell. Colour, brown. Compare Vines, 1896, p. 135, fig. 95 b.
m. Cast of a plant-cell with scalariform pitting. This contains a good chalcedony spherulite, shown as between crossed nicols. Colour, brown.
n. Cast of a plant-cell. Colour, brown. The contained granular matter suggests the remains of the original contents.
o. Casts of a group of tracheids with scalariform pitting and on the right a trace of a perforation-plate.
p. An entire single scalariform pitted tracheid. Colour, brown.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TEXT-FIG. 2

in the infusorial earth of Bissex Hill, Barbados, but no good spherulites have been seen in them. The rods sometimes have a turbid core. Turbidity also occurs occasionally in the Bissex Hill spicules.

By transmitted light most of the bodies are colourless but many, particularly those of vegetable origin, are brown or yellow. Schulze (1900) described the effect of heating to redness on certain sponge-spicules (pl. xlvi and text, p. 235). One that turned brown is figured. Seeing that it is almost certain that this rhyolite-ash came from the now extinct Toba volcano in North Sumatra, heating during the great eruption that threw the ash into the air may explain the brown colour seen in some of the bodies. When I heated some of the ash in a muffle for an hour (1930, p. 389) an opaque centre was developed in some rods and some split down the centre, but no brown colour was produced in rods previously colourless. This may have been due to absence of organic matter or to its having been completely burned away by the high temperature.

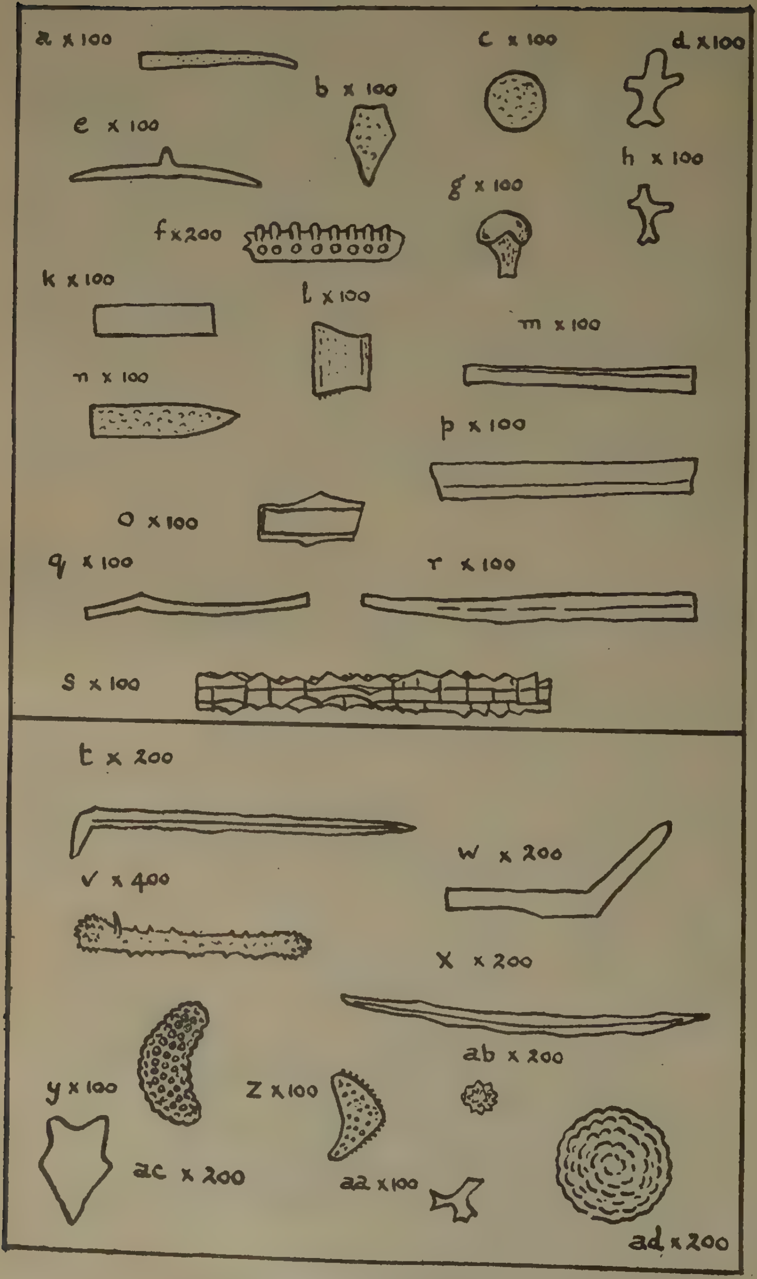
In cases where the ash has become compact the cementing material in specimens examined by me is chalcedony. In sample No. 3 detached pieces of chalcedony with characteristic double refraction are common. Opal has not been seen as a cementing material nor filling tubules or spherical cavities in the pumice.

THE PLANT REMAINS

The plant-remains are shown in plate I and text-figures as detailed in the legends. With the exception of a–d in text-figure 1 all come from sample No. 3. Associated with them are, in text-figure 2, objects of doubtful nature (b, d, e, m, o, p, and s), a diatom (h), a sharply terminated

TEXT-FIG. 2

a. A plant-cell. The serrated edges are caused by oval pits that are shown diagrammatically over parts of the cell only. They are clearest at the top end where the wall is thinnest. At the top end also there is a trace of an internal tubular cavity. Colour, brown.
b. Nature doubtful. Left part brown, right colourless, but contains some granular opaque matter. No plant-pits visible. It has some resemblance to the polyzoan *Valkeria atlantica*. See Harmer, 1915, pl. vi, figs. 10–12.
c. Part of a plant-cell with long pits. Colourless.
d. Nature doubtful: resembles b. Pale brown.
e. Nature doubtful: resembles b. Brown.
f. Part of a lithistid sponge-spicule ? Colourless.
g. Lithistid sponge-spicule ? Partly brown.
h. A diatom.
k. A club-shaped body: one of the few seen with the plant-cells. Pale brown; surface glossy.
l. Nature doubtful. Yellow and covered with minute tubercles. It may be a sponge-spicule or a cast of a plant-cell with simple circular pits.
m. Nature doubtful. Pale brown.
n. A plant-cell. Brown and partly opaque but the structure can be seen as shown diagrammatically with strong illumination.
o. Nature doubtful. Left colourless, right brown.
p. Nature doubtful. Brown. There is one chalcedony spherulite.
q. A monaxon sponge-spicule, the only one found in sample No. 3. Colourless. It has an axial canal.
r. A pitted plant-cell with included opaque matter.
s. Nature doubtful. Light brown, on the left extremity a few minute tubercles are visible.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ab x 200
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z x 100
ac x 200
aa x 100
ad x 200

TEXT-FIG. 3

monaxon (q), and three objects (f, g, k) that may also be sponge remains. Those lettered b–s above are very puzzling. They do not show any evidence of having possessed pitted or sculptured membranes, but some have granular surfaces, and Drs. Metcalfe and Hare could not recognize them as vegetable structures. Somewhat similar things occur in the Malacca padi-field soil (text-figure 3). Only one monaxon spicule was found in sample No. 3. Other diatoms occur. Dr. Oakley (1940, p. 290) says that all the diatoms he found in this specimen are of freshwater origin.

After examining my specimens Drs. Metcalfe and Hare were able to speak with confidence of the vegetable origin of some of them and of their having been derived from Pteridophyta and Dicotyledons, but more than that could not be said. They are certainly terrestrial and silicification could have been effected by hot springs near the Toba volcano. The fact that no large fragments of opalized wood or fern-tissue have been found in the ash in Malaya can be explained by the ash being wind-borne, which would be impossible for heavy pieces. They do not help in determining the age of the ash, but they prove that as they were certainly not siliceous originally, so also may the other opaline bodies have been other than siliceous originally, excluding those which are obviously monaxon and spheraster spicules of sponges.

Text-fig. 3

From soil in a Malacca Padi-field

a. Nature doubtful. Faintly marked.
b. Club-shaped body, marked by solution-pitting.
c. Brown sphere.
d. Lithistid sponge-spicule ? Brown.
e. A triaene sponge-spicule. Colourless.
f. Cast of plant-cell with pits ?
g. Club-shaped body. Compare text-figure 4, fig. v.
h. A lithistid sponge-spicule ? Colourless.
k. A rod.
l. Part of a rod showing spines.
m. Cast of a plant-cell ? Brown.
n. Pointed rod much pitted by solution.
o. A plant-cell ? Colourless. This is evidently hollow.
p. A plant-cell ? Yellow.
q. A plant-cell ? Brown.
r. A plant-cell ? Brown.
s. A rod sculptured by extreme solution-pitting ? Microphoto. Scrivenor, 1930, pl. xxiii, fig. 2.

From ash collected at the landing-place, Tanjong Perak Estate

t. An angulate skeleton-spicule of a sponge. Colourless.
v. A flesh-spicule of a sponge. Colourless.
w. A geniculate skeleton-spicule of a sponge. Colourless.
x. A skeleton-spicule of a sponge. Colourless. The wavy outline is slightly exaggerated.
y. A colourless tuberculated sponge-spicule ? Sollas, 1888, pl. xxviii, figures a somewhat similar spicule from *Erylus formosus*.
z. Nature unknown. It may be a sponge-spicule.
aa. A lithistid sponge-spicule ?
ab. A spheraster. Colourless.
ac. A club-shaped body. Colourless.
ad. A tuberculated sphere. Colourless.

A few spherasters occur in sample No. 3, also larger spheres with tuberculated or smooth surfaces.

Pl. I, fig. a, is an example of a few thin plates strongly resembling a cross-section of wood-fibres. Two specimens have been seen that might be bundles of such cells but they are not satisfactory evidence, and in the case of the plates it is difficult to understand how, if it is of vegetable origin, a thin cross-section could have been formed by any natural process. In view of the difficulties mentioned, and on account of the shape of the fragment, it seems more likely that this is part of a vessel element with crowded bordered pits—i.e. if it is of vegetable origin at all, which seems doubtful. Optical properties point to it being composed of opal. Nothing like it has been seen in the specimens of infusorial earths, etc., that I have examined for comparison.

Pl. I, fig. d, is typical of several bodies with an external spiral groove and longitudinal striae. Drs. Metcalfe and Hare are doubtful if this is of vegetable origin at all, but there is a remote possibility that it might be a vessel element with spiral thickening. Dr. Oakley figured a similar specimen (1940, p. 291). An idea for which I alone am responsible is that these objects and the doubtful objects in text-figure 2 (*supra*) may have some connection with annelids or polyzoa.

Pl. I, fig. h, is of a very curious object found in sample No. 3, but unfortunately lost while transferring it to a permanent mount. The photograph was taken while it was mounted in clove-oil. It may be a cast of a vegetable cell with annular pitting or a sponge-spicule with annular ridges (see legend).

SPECIMENS IN SOIL FROM A PADI-FIELD IN MALACCA

These were mentioned in my 1930 paper and in pl. xxiii some were figured. In text-fig. 3a–s, of this paper are drawings of other specimens described in the legend. Fig. s is of the same object as microphotograph 2 in pl. xxiii of the 1930 paper. I have found similar things in samples from Tanjong Perak Estate and am inclined to think now that the very irregular outline is due to extreme solution-pitting. This soil contains many corroded rods, much recent vegetable matter, some showing cellular structure, and other objects of which the drawings are examples. A search for pumice-fragments has resulted in only two being found, and one of those is doubtful. West to W.S.W. winds would blow pumice from the Toba volcano to all the localities where these opaline objects have been found in Malaya. In the Malacca soil, solution which has had a very marked effect on most of them, may have almost entirely destroyed grains of pumice.

SPECIMENS FROM AN ARTIFICIAL LAKE AT KROH

In 1930 (p. 388 and pl. xxiii) I mentioned " monaxons, some coloured brown, and spherasters " in mud from an artificial lake at Kroh in the north of Perak, at an altitude of 1,000 feet. Re-examination of the three slides available shows that recent vegetable matter and mineral grains form the bulk of the mud. Siliceous rods much pitted by solution are common and there are a few small club-shaped objects. Spheres with tuberculated surface occur and there are many small bodies that may be spherasters, but only one fragment of a monaxon with axial canal has been seen. No pumice is visible though wind could easily convey it from the Toba volcano. The material examined, however, is too limited to say that there is no pumice in the mud or the neighbouring soil.

RHYOLITE-ASH FROM THE LANDING-PLACE ON THE RIVER-BANK, TANJONG PERAK ESTATE

The slides 7729 A–G are from this ash, in which diatoms are common, all apparently of freshwater origin. Specimens of other things found are figured in pl. I, figs. c and g, and in text-fig. 3 t–ad. In the plate are a pointed, tapering monaxon with axial canal and spine, and on the right a spheraster; also a good example of spiny amphidiscs found in this sample. Spherasters are common, but tuberculated spheres less so. Several flesh-spicules such as fig. v of text-fig. 3 have been found.

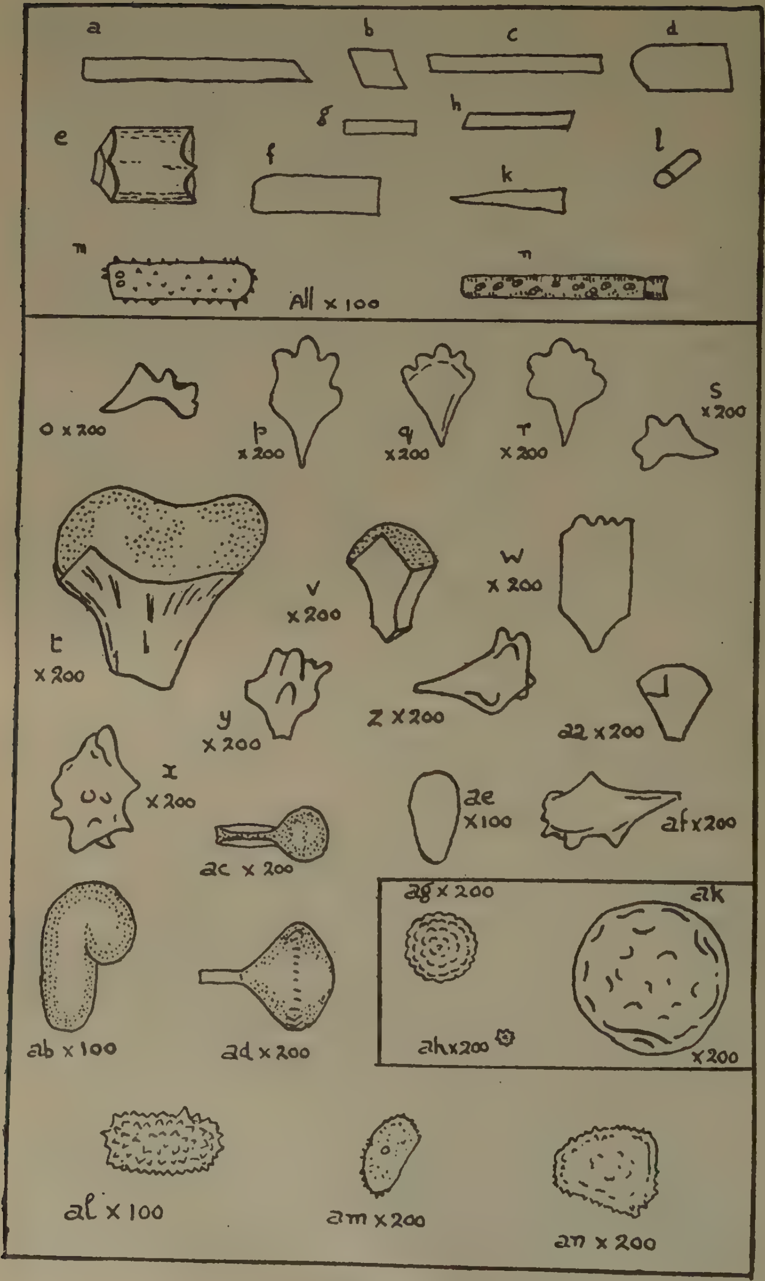
Dr. Oakley tells me that the spherasters show that these sponge-spicules are marine because no freshwater sponge with spherasters is known. Annandale (1918) certainly makes no mention of them, and I cannot find reference to them in any freshwater sponge elsewhere. All the spicules in pl. I, c and g, and text-fig. 3, t, v, w, and x, might be from Asiatic freshwater sponges. Annandale mentions axial canals in *Spongilla geei*. In assemblages of freshwater spicules that I have examined, e.g. in the diatom-earth of Toome Bridge, N. Ireland, monaxons with and without canals occur. The same applies to marine assemblages such as that of Bissex Hill. Dr. Oakley's dictum that an axial canal is an essential and striking feature of the unaltered monaxon spicule of a siliceous sponge is therefore untenable for either freshwater or marine sponges; but, although as a test of whether a single rod is a sponge-spicule or not, the absence of a visible canal is useless, it is a very different matter when a large number of siliceous rods fail to show a visible canal in any case.

THE RODS, SPHERES, AND CLUB-SHAPED BODIES

Text-fig. 4 contains drawings of a selection of these, the most numerous objects in the ash, with one plant-cell (fig. n) for comparison.

The rods are often pitted by solution. I have seen less pronounced pitting on spicules from a bath-sponge. Several of the rods have spines projecting from them, fig. m being the best example found. While examining the rods Dr. Hare noticed one of these spiny specimens and said he could not refer it to any vegetable structure he knew. Both he and Dr. Metcalfe could not feel confident that the rods without spines were casts of any plant-cells. On the other hand such spines are common on sponge-spicules, e.g. in the genus *Iophon* (Wilson, 1904, pl. 20, figs. 5, 8, 10). It will be noted that the rods sometimes have an inclined termination. This is seen in broken spicules occasionally. Pointed terminations as in fig. k are not common, but most of the rods might be spicules with rounded ends, though comparison with assemblages of known sponge-spicules does not encourage that view.

As the plant-cells have been silicified the rods also may be something that was not siliceous originally. Calcareous sponge-spicules, for instance,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TEXT-FIG. 4

might be replaced by silica, and they have no axial canals in the specimens I have examined. It is difficult to understand, however, how any marine organisms could have been silicified by springs on the Toba volcano unless contained in much older rocks.

Assuming that the rods were siliceous from the beginning, there are at least two objections to their being broken sponge-spicules. The first is that when heated in a muffle some of them split down the central axis, whereas monaxon sponge-spicules, which grow concentrically round a filament, would be expected to break up concentrically unless there had been some molecular change. The other objection is that although some spicules show no axial canal, in all the assemblages of detached spicules that I have examined others show clearly visible canals. There is a possibility that the rods are spicules of one sponge-species without visible axial canals in its monaxons, but their being siliceous sponge-spicules of any kind would be more credible if some did show canals.

Specimens from the sea close by in The Dindings show spicules with canals.

Fig. ae is of special interest. Yellow and with a smooth surface, it agrees in shape with a well-known form of sponge-spicule, e.g. in *Hymeraphia simplex* (Bowerbank, 1864, vol. iii, pl. lxxx). This, and the spiny rods, are evidence of some sponge-spicules being in the ash at any rate among the rods, but none shows a canal

TEXT-FIG. 4

a.	A rod. Brown.
b.	Rhomboidal fragment of a rod. Colourless.
c.	A rod. Colourless.
d.	A round-ended rod. Colour brown.
e.	Part of a thicker rod. Colourless.
f.	A rod. Colourless.
g.	A rod. Brown.
h.	A rod. Colourless.
k.	A pointed rod. Colour brown.
l.	A rod showing circular cross-section. In a few cases the cross-section is roughly hexagonal or angular, which is more likely to occur in a plant-cell than in a sponge-spicule.
m.	A spiny rod. Colourless. No axial canal. Several spiny rods occur, some brown. This is the best example. They show no plant-pitting.
n.	A plant-cell with twin-pits, included for comparison with the rods which show solution-pitting only.
o–aa.	Club-shaped bodies ; w is pale brown, the rest colourless. Figs. t and v are unusual types. Compare Text-figure 3, g.
ab.	Club-shaped body, brown with granular surface. The only one of this type seen.
ac.	Club-shaped body. Brown. See text.
ad.	Club-shaped body. Stem colourless, rest brown. See text.
ae.	A sponge-spicule. Yellow. Compare e.g. Bowerbank, 1864, iii, pl. lxxx, *Hymeraphia simplex*.
ag.	Tuberculated sphere. Colourless.
ah.	A sponge spheraster.
ak.	A large sphere marked by solution-pitting. Colourless.
al.	Spiny body resembling a spicule from *Hymeniacidon* ? See Hinde and Holmes, 1892, pl. 7, fig. 43.
am.	Irregular spiny body. Colourless.
an.	Irregular spiny body. Colourless.

The spheres are illustrated in pl. I and text-fig. 4. In the latter fig. ah is a spheraster marking the smallest of the spherical objects : ak is one of the largest spheres showing solution-pitting on its otherwise smooth surface. The tuberculated spheres are intermediate in size. The smooth are the commonest. The small spherasters have short spines. The tubercles may be spines affected by abrasion, but it cannot be regarded as proved that these objects form a series in the largest of which the spines have been entirely worn away. Bodies similar to the tuberculated sphere in pl. I, fig. b, are known among sponges ; e.g. in *Geodia stellata* (Lendenfeld, 1906, pl. xxxvi, figs. 35, 36), in *Calthropella simplex* (Sollas, 1888, pl. x, fig. 28), in *Cydonium eoaster* (ibid., pl. xxi, fig. 23), and in *Placospongia melobesioides* and *P. carinata* (Vosmaer, 1902, pl. iv). The closest resemblance is in *Cydonium eoaster*.

If the larger spheres had smooth surfaces from the beginning they resemble the smooth silica-pearls described by Schulze in Lyssacine fragments from the Bay of Bengal and in *Pheronema giganteum* (1902, pl. ix, fig. 14). Tuberculated silica-pearls are shown in the same plate. In 1888 (fig. x, j) again, Sollas shows a plain sphere as being a spicule of the Monaxonida, and on p. lxii says that globules or spherules occur in the *Tetillidae* and *Caminus sphaerocoma*. Fristedt figures globular spicules (1885, pl. 1, figs. 49, 50).

Drs. Metcalfe and Hare were not inclined to the view that these spheres might be silicified pollen-grains.

The club-shaped objects, selected specimens of which are shown in text-fig. 4, are not matched by anything I can find in the literature on sponges or elsewhere. No two are exactly alike. With the exception of a few, such as the extraordinary thing in fig. t, which may be the ends of broken spicules, most of them appear not to be fragments but entire objects, and perhaps flesh-spicules of some unrecorded sponge. None shows a canal. Tubercles are common and sometimes spines are seen on them. Irregularly shaped—not club-shaped—bodies also occur, with tubercles (fig. x), or with spines (figs. al, am, an). Fig. al resembles a sponge-spicule figured by Hinde and Holmes (1892, pl. 7, fig. 43).

The nearest sponge-spicules that I can find to the knob-shaped things figs. ae, ad, are figured by Ijima (1926, pl. x, *Farrea*, and 1901, pl. ii sphaerohexasters), and by Kirkpatrick (1908, pl. 12, figs. 8a, 9–12 sphaerostyles), but the resemblance is not close. There are a few things in my slides that might be detached ends of large amphidiscs.

CONCLUSION

If marine sponge-remains occur in this ash there is a case for assumin that the sea-level in post-Pleistocene time was once 200 feet higher than now. The brown colour of many of the objects described suggests baking but only a submarine volcano could bake recent marine organisms, an a rise of 200 feet would not make the Toba volcano submarine or anything near it. Marine spicules could be incorporated by wind, but if s what does the brown colour, as in the Kroh specimens, mean ? If al these strange things were derived from the neighbourhood of the Tob volcano then organisms containing them should still be alive in Toba Lak and its vicinity.

Dr. Oakley tells me the skeleton-spicules and spherasters in the ash from the landing-place for Tanjong Perak Estate are marine because no freshwater sponge is known with spherasters ; but they are associated with freshwater diatoms and neither in this specimen nor in any other from the estate have any undoubted remains of radiolaria been seen, such as occur in marine sponge-assemblages I have examined. None of these skeleton-spicules or spherasters is brown, so they seem to have escaped volcanic baking, which suggests that their place of origin is different from that of the things that have been baked brown. It is permissible to ask if a monaxonid freshwater sponge could possibly produce spherasters ? From what Miss I. B. J. Sollas (1936, pp. 233, 234) and the late Professor W. J. Sollas (1888, fig. x, j) have published I gather it is not impossible. In Lake Chini (marked on my map with the 1930 paper as about 45 miles inland on the south bank of the Pahang River) monaxon spicules and spherasters occur with freshwater diatoms and without a trace of anything obviously marine. If the spicules are marine then Lake Chini was under the sea not very long ago ; but until the sponge from which the spicules came is found, and I venture to think it may prove to be a freshwater sponge, that point cannot be regarded as settled.

To summarize this involved subject :—

1. Some of the bodies are derived from silicified higher plants and may have come from the Toba volcano in North Sumatra.
2. Undoubted sponge-spicules occur in the ash and are regarded as marine because of the presence of spherasters. If that is correct then the recent spicules in Lake Chini are marine also and the sea was 200 feet higher than now not long ago, but a freshwater sponge with spherasters may yet be found.
3. There is evidence for the rods, spheres, and club-shaped objects being sponge-spicules but evidence against that view has been given. The spheres agree closest with known sponge-spicules ; but the nature of all these bodies cannot be regarded as proved until the parent organism or organisms are found.

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EXPLANATION OF PLATE

a. A thin, colourless opaline plate somewhat resembling part of a pitted vessel element. Five of these plates have been seen in sample No. 3 from Tanjong Perak Estate.

b. A sphere with tuberculated surface resembling a blackberry or golf-ball. Colourless. These are not so abundant as the smooth surfaced spheres, nor so large. Tanjong Perak Estate.

c. A monaxon skeleton-spicule with tapering, pointed end and axial canal. It has one spine. Annandale (1918, p. 204) figures *Spongilla stanleyi* as having one or two spines. On the right of the monaxon is a spheraster. Both colourless.

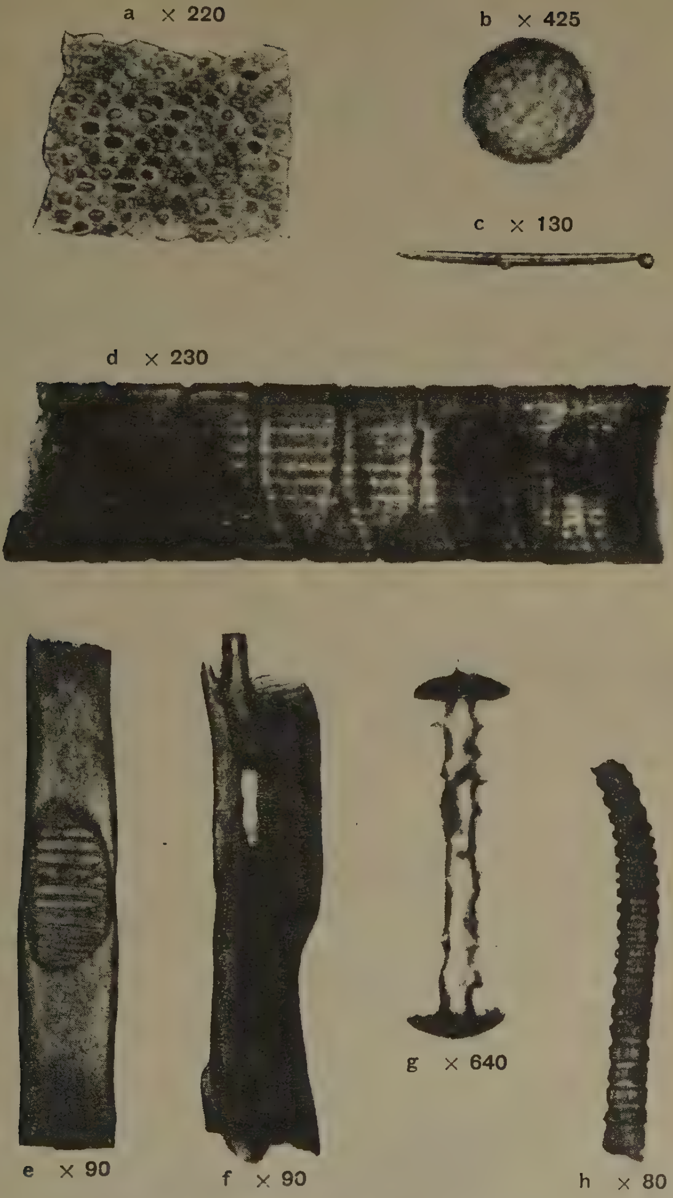
d. Nature unknown. A rod-like body with external spiral groove and longitudinal striae. On the right are two included spheres of chalcedony formed by the alteration of the opal. Colour brown. Other similar bodies have been found in sample No. 3 from Tanjong Perak Estate.

e. Vessel element of a higher plant with scalariform perforation-plate. Colour brown. Compare Eames and MacDaniels, 1925, p. 65, fig. 35A and C. From sample No. 3 Tanjong Perak Estate.

f. A group of vessel elements from a higher plant with scalariform pitting and perforation plates. Colour brown. From sample No. 3, Tanjong Perak Estate.

g. A spiny amphidisc, probably a gemmule-spicule but may be a flesh-spicule. Colourless. See text-figure 3 for associated spicules in the slides 7729 A–G. Landing-place for Tanjong Perak Estate. Several spicules such as this have been seen in the slides.

h. A yellow body with regularly arranged rings and longitudinal striae. It may be a cast of a plant-cell with annular pitting, compare Eames and MacDaniels, p. 94, fig. 48D, or a sponge-spicule with annular ridges, compare Hinde and Holmes, 1892, pl. 7, figs. 21 and 38 ; also Hinde, 1885, pl. 40, figs. 11 and 13, and pl. 42, fig. 9. From sample No. 3 Tanjong Perak Estate. See also text-figure 1, fig. k.



a × 220

b × 425

c × 130

d × 230

e × 90

f × 90

g × 640

h × 80

Microphotos by J. B. S.

ORGANIC REMAINS IN RHYOLITE ASH.

Growth Stages in some Species of *Promicroceras*

By Ethel D. Currie

In a recent study of the growth stages of *Promicroceras marstonense* (Currie, 1942), it was shown that apart from slight individual variations, the growth-ratios exhibited changes at certain stages, which are characteristic of the species. A similar investigation has now been carried out with material representing other species of *Promicroceras*, in order to ascertain how far there is general agreement within the genus and the extent to which any differences are typical of the various species studied.

The material used was a collection of small pyritized specimens of *Promicroceras* from the Lias of Dorset collected by Dr. W. D. Lang who gave them to Professor A. E. Trueman for study. Dr. L. F. Spath has kindly named most of the specimens (as *P. capricornoides* (Quenstedt), *P. pyritosum* Spath, etc.), and he has pointed out the difficulty of identifying with certainty some of these immature specimens. Dr. Spath has also informed me that this material is probably from Bed 81 (*capricornoides* sub-zone) (Lang and Spath, 1926, pp. 150 and 160–1).

The methods used were those described in the paper referred to above (Currie, 1942). In grinding, many of the pyritized specimens broke up and the structure was not clear in a number of cases. Fourteen reasonably complete sections were obtained, however, although in a few of these the innermost whorls were lost.

MEDIAN WHORL HEIGHT

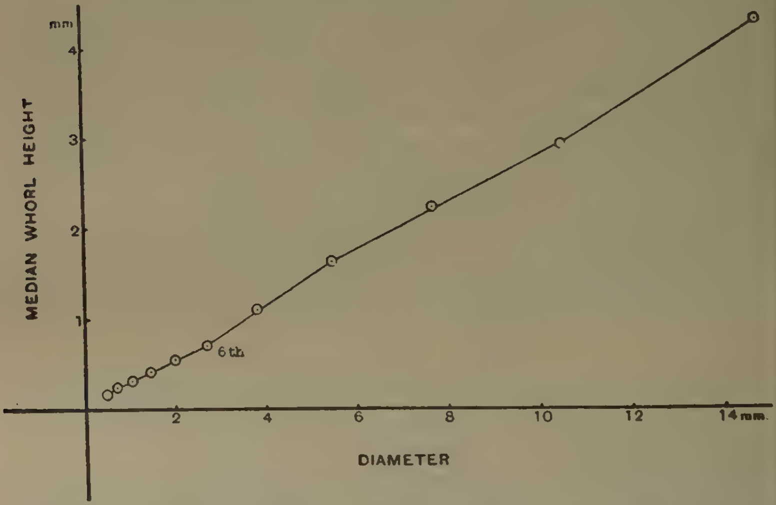
Median whorl height was measured on all the sections, and for each specimen graphs were drawn of (*a*) median whorl height plotted against diameter of shell, and (*b*) logarithmic plotting of the median whorl height at half-whorl intervals. The graphs show certain characteristic features in which they all agree generally with comparable graphs of *P. marstonense* (Currie 1942, figs. 2 and 3). The following changes of gradient are noteworthy :—

1. Between the 2nd and 3rd half-whorls (seen in all the sections in which the initial whorls are preserved) at a diameter of about 0·75 mm.
2. At about the 6th half-whorl at a diameter of 2·2–2·97 mm.

Two further changes, one at about the 8th–10th half-whorl and a second at a half-whorl to one whorl later, are seen in the specimens under discussion, but not in *P. marstonense* (although one or two graphs of *P. marstonense* showed a slight suggestion of a change of gradient at the 10th half-whorl : Currie, 1942, p. 347). The first of the two changes of gradient corresponds to an increase, the second to a decrease of spiral angle.

The change between the 2nd and 3rd half-whorls is not easily studied in transverse sections, since the dimensions at half-whorl intervals are inadequate for complete representation of the features, but it is clear that this change is more marked than those which follow. It is possible, as Trueman has suggested (1941, p. 366), that this change corresponds with the change from embryonic to post-embryonic growth. Professor Trueman believes that in the ammonites, the embryonic shell included at least a part of the whorl succeeding the protoconch. A similar view was held by Bodylevsky (1926) who regarded a constriction three-quarters of a whorl beyond the first suture line in *Cadoceras elatmae* Nik. as marking the end of the embryonic shell.

The change in growth gradient about the 6th half-whorl (where the shell is 2·2–2·97 mm. in diameter) is well marked in all sections showing this stage. As in *P. marstonense* the change indicates a decrease of spiral angle. The spiral angle of the shell between the 3rd and 6th half-whorls (α_1) was calculated for several specimens and was found to be in the region of 85°. The actual values obtained were 85° 24′, 85° 21′, 85° 11′, 85° 7′, 85° 2′, 84° 59′ 84° 46′, and 84° 35′ compared with an average of 85° 31′ for *P. marstonense*.



Text-fig. 1.—Graph showing rate of increase of median whorl height in relation to diameter of shell, in a specimen of *Promicroceras capricornoides* (PL17), based on measurements of a median transverse section at half-whorl intervals from the first half-whorl onwards. Note changes of growth gradient between the 2nd and 3rd half-whorls and at the 6th, 8th, and 10th half-whorls.

The subsequent changes in growth gradient show a wider range of variation in the sections studied than those just described. It is convenient to refer them to four types, not in all cases very sharply distinguished from one another. It is interesting to note that the separation of the specimens into groups corresponding with these four types is related in some way to their grouping with the different species *P. capricornoides* and *P. pyritosum*, but there is not complete correspondence between them. Generally speaking the specimens identified as *P. capricornoides* are concentrated in groups 1 and 2 while the typical specimens of *P. pyritosum* fall into groups 3 and 4. Details concerning these changes are summarized in the table below.

The specimens referred to groups 1 and 2 show very slight differences. In the graphs of group 1 (Text-figs. 1 and 2) there are changes of growth

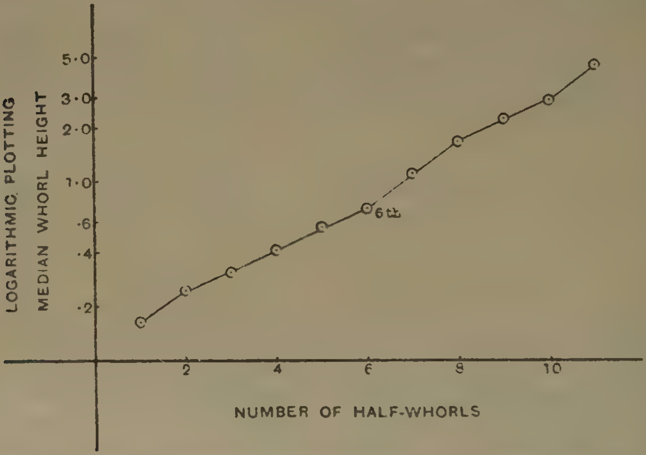
		Increase of Spiral Angle.		*Decrease of Spiral Angle.*	
		Half-whorl.	*Diam. mm.*	*Half-whorl.*	*Diam. mm.*
Group 1.					
PL17	*Promicroceras capricornoides*	8th	5·5	10th	10·5
PL19	*Promicroceras capricornoides* (closely ribbed variety)	8th	4·6	10th	9·2
PL18	*Xipheroceras*	8th	4·8	10th	9·3
PL1	Specimen destroyed	8th	4·8	10th	9·1
PL3314	? *Promicroceras pyritosum*	?8th	5·2	?10th	9·6
Group 2.					
PL267	*Promicroceras capricornoides* (closely ribbed variety)	8th–9th	4·8–6·7	10th	9·3
PL3270	*Promicroceras capricornoides*	9th	7·2	10th	9·8
PL2	*Promicroceras capricornoides*	9th	6·3	10th	8·5
PL271	*Promicroceras capricornoides*	?9th	8·4	?10th	11·5
PL3317	*Promicroceras capricornoides*	?9th	7·4	?10th	10·2
Group 3.					
PL3275	*Promicroceras pyritosum*	?–10th	7·3–10·3	?11th	13·9
PL3273	*Promicroceras* sp.	?10th	9·1	?11th	12·2
PL3	*Promicroceras pyritosum*	10th	11·0	11th	15·0
Group 4.					
PL473	*Promicroceras pyritosum*	9th	6·8	11th	12·5

gradient at the 8th half-whorl (diameter 4·6–5·5 mm.), and at the 10th half-whorl (diameter 9·1–10·5 mm.) ; in the graphs of group 2 (text-fig. 3) the corresponding changes occur at the 9th half-whorl and at the 10th half-whorl (diameter 8·5–9·8 mm.). In both cases the changes represent an increase followed by a decrease of spiral angle. The distinction may possibly be accounted for by the fact that the sections are differently oriented with reference to the first septum, for example, and give dimensions at half-whorl stages only ; the difference may only indicate a general tendency for the change to occur before or just after the 9th half-whorl stage.

The changes of gradient in the graphs of specimens referred to group 1 vary in amount in different graphs and in one (PL1) the changes are so small that the graph from the 6th half-whorl onwards approximates to a straight line as in *P. marstonense*. The specimens with graphs of this type include, according to Dr. Spath's tentative identifications, a young individual of *P. capricornoides* (PL17), a more closely ribbed variety of *P. capricornoides* (PL19) which may be transitional to *P. precompressum*, a young *Xipheroceras* (PL18) and a specimen that might be *P. pyritosum* (PL3314).

One graph (PL267) included in the second group shows the first change of gradient between the 8th and 9th half-whorls thus linking up the graphs of types 1 and 2. Specimens giving the second type of graph include a young *P. capricornoides* (PL3270) and a more closely ribbed variety of *P. capricornoides* (PL267) very similar to the closely ribbed variety referred to in group 1 (PL19). Two larger specimens (PL271 and PL3317), identified as young *P. capricornoides*, are tentatively referred to this group although they are incomplete in the central whorls. It is deduced from the dimensions that the changes occur at the 9th half-whorl (diameter 7·4 and 8·4 mm.), and at the 10th half-whorl (diameter 10·2 mm. and 11·5 mm.). The amounts of the changes of gradient in the graphs of this group vary slightly, showing a tendency to flattening in the two larger specimens.

The graphs of the third type are based on three specimens, in two of which the early whorls are not preserved. The graphs of this type also show two changes of gradient at an interval of one half-whorl. The changes of spiral angle vary in amount, being considerable in two graphs and slight in the third (PL3); and they occur at different diameters, but it is deduced that they occur at the 10th and 11th half-whorls respectively. The first change in one (PL3275) occurs slightly before the 10th half-whorl measurement suggesting that this group may merge with group 2. The first change occurs at diameters from 9·1 mm. to 11·0 mm., and the second at 12·2 mm., 13·9 mm., and 15·0 mm. One of the specimens giving rise to this type of graph is identified by Dr. Spath as a typical *P. pyritosum* (PL3275).

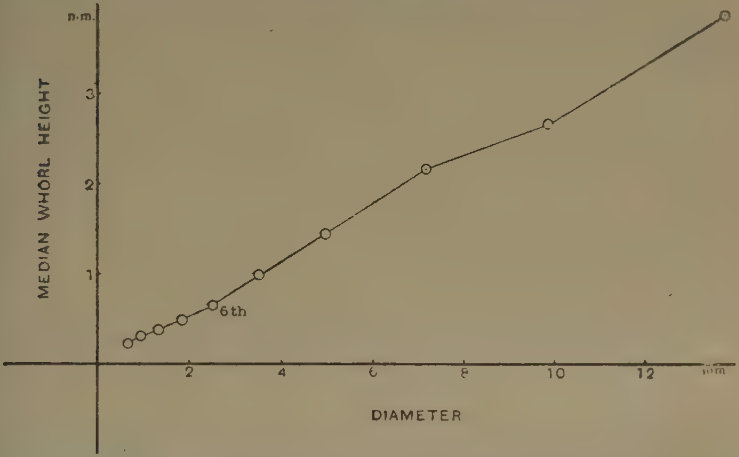


Text-fig. 2.—Graph showing logarithmic plotting of median whorl height at intervals of one half-whorl, based on the same section (PL17) as in Text-fig. 1.

The fourth type of graph which is based on only one specimen shows only slight changes of gradient at the 9th and 11th half-whorls (diameters 6·8 mm. and 12·5 mm.). It thus approximates to the straight line graphs of *P. marstonense*. This graph is based on a specimen described as a typical *P. pyritosum* (PL473).

Maximum Whorl Breadth

Maximum whorl breadth was measured in all the sections and a graph was drawn of maximum whorl breadth in relation to diameter for each specimen. These graphs show certain features in common, in respect of which they also show agreement with corresponding graphs of *P. marstonense* (Currie, 1942, p. 357). They show no increase of breadth in the first two half-whorls which have the same breadth as the protoconch. As in *P. marstonense* also, maximum whorl breadth from the 2nd half-whorl onwards is proportional to the diameter but not uniformly so. From the 2nd to about the 6th half-whorl, maximum whorl breadth increases rapidly ; beyond that stage the rate of increase is reduced. In *P. marstonense* the corresponding reduction in growth gradient occurs at the 8th half-whorl. There is agreement therefore among all these graphs of *Promicroceras* up to the 6th half-whorl.



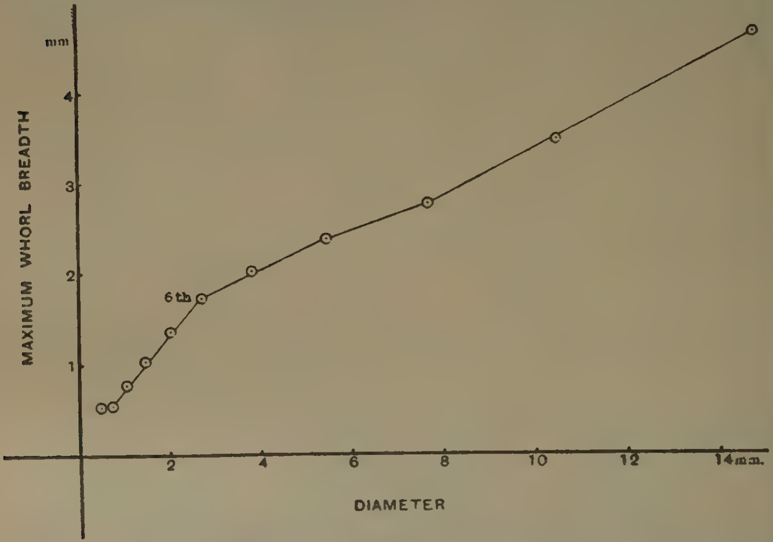
TEXT-FIG. 3.—Graph showing rate of increase of median whorl height in relation to diameter of shell, in a specimen of *P. capricornoides* (PL3270), based on measurements of a median transverse section at half-whorl intervals from the second half-whorl onwards. Note changes of growth gradient at the 6th, 9th, and 10th half-whorls.

Beyond the 6th half-whorl, in the graphs of the specimens under discussion, there are two, in a few specimens three, changes of gradient between the 8th and 11th half-whorls. The first change occurs at the 8th or 9th half-whorl and is usually a decrease of gradient, but in some graphs it is an increase. The second change which occurs at a half-whorl or a whorl later is an increase of gradient where the previous change is a decrease and vice versa.

As in the case of graphs of median whorl height it is convenient to describe these graphs of maximum whorl breadth in four groups although these groups are probably not sharply divided one from another. It may be of interest to note that according to their graphs of maximum whorl breadth the specimens fall, with two exceptions (PL2 and PL_3), into the same four groups as those already referred to, based on graphs of median whorl height.

The graphs of maximum whorl breadth in the first group (text-fig. 4) show changes of growth gradient at the 8th and 9th half-whorls, at the former a decrease, and at the latter an increase of gradient. The amounts of the changes of gradient vary slightly in the different graphs.

Graphs of maximum whorl breadth of the second type show changes of growth gradient at the 9th and 10th half-whorls respectively. Two of the graphs (PL3270 and PL267) which agree closely, show a rise of gradient at the 9th half-whorl and a fall at the 10th, but a third graph (PL2), one of the exceptions referred to above, shows a fall at the 9th and a rise at the 10th. The other two graphs in this group show changes of gradient, first an increase, then a decrease, at what are probably the 9th and 10th half-whorls. The amounts of the changes are considerable in one graph and slight in the other.



TEXT-FIG. 4.—Graph showing rate of increase of maximum whorl breadth in relation to diameter of shell, based on measurements of the same section (PL17) as in Text-figs. 1 and 2, at half-whorl intervals from the first half-whorl onwards. Note changes of gradient at the 2nd, 6th, 8th, and 9th half-whorls.

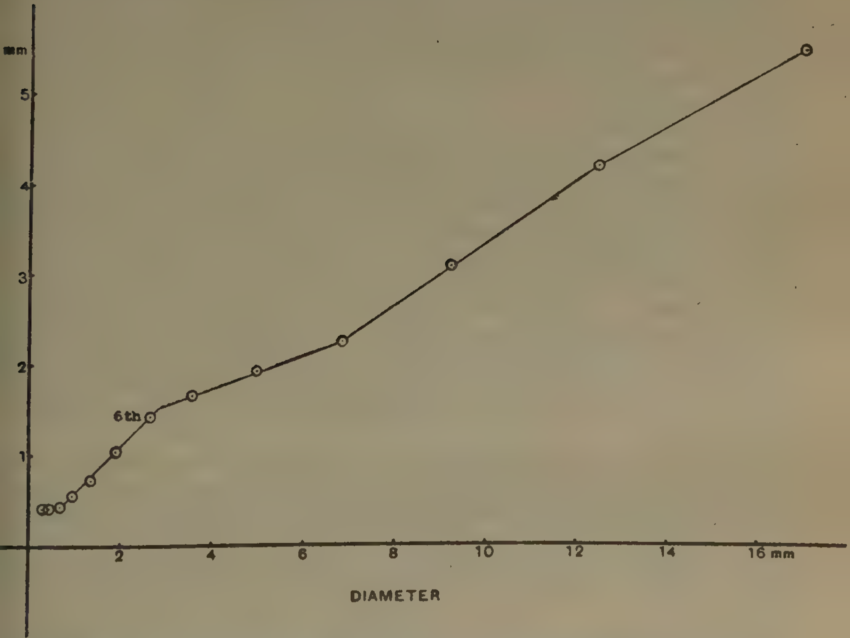
Graphs of maximum whorl breadth in the fourth group (Text-fig. 5) show an increase of gradient at the 9th and a decrease at the 11th half-whorl. The decrease in gradient at the 11th half-whorl in one graph (PL3) which actually occurs slightly before the 11th half-whorl measurement, is more marked than that of the other graph (PL473).

The graphs of maximum whorl breadth of the third type are both incomplete, and owing to the state of preservation of the sections, probably not quite accurate. Nevertheless they both show a decrease followed by an increase and then a decrease of gradient at what are probably the 9th, 10th, and 11th half-whorls respectively. The amounts of the changes of gradient are much greater in one graph (PL 3275) than in the other (PL3273) ; in fact the change at the 11th half-whorl in PL3273 is almost negligible. These differences may be partly due to the sections not being quite median.

It should be noted that variations in the amounts of the changes between the 8th and 11th half-whorls in graphs of both median whorl height and maximum whorl breadth probably depend to some extent on the position of the section which may pass through a rib or between ribs.

DEPTH OF IMPRESSED AREA

Depth of impressed area is difficult to measure accurately and unfortunately few specimens allowed of reasonably accurate measurement of this dimension. The graphs based on these specimens, allowing for some irregularities due to difficulties in measurement, are similar to one another. The first two half-whorls are not represented in any of the graphs. From the 3rd to about the 6th half-whorl the rate of increase of depth of impressed area which is proportional to diameter of shell is rapid. Beyond the 6th half-whorl to the 10th or 11th, there is practically no increase, but in the 11th or 12th half-whorl there is a slight increase. In corresponding graphs of *P. marstonense* (Currie, 1942, p. 354) the main change of growth gradient is at the 8th half-whorl.



TEXT-FIG. 5.—Graph showing rate of increase of maximum whorl breadth in relation to diameter of shell, in a specimen of *Promicroceras pyritosum* (PL473), based on measurements of a median transverse section at half-whorl intervals from the protoconch onwards. Note changes of gradient at the 2nd, about the 6th, and at the 9th and 11th half-whorls.

CONCLUSIONS

Although only some fourteen fairly complete sections of *P. capricornoides*, *P. pyritosum*, and related variants are available for study, taken with the results of work on numerous sections of *P. marstonense*, they give evidence of a certain uniformity in the growth stages of all the species of *Promicroceras* investigated. Preliminary studies on the growth gradients of other genera (*Emileia*, *Sphaeroceras*, *Chondroceras*) suggest that certain features are characteristic of *Promicroceras*.

The marked change between the 2nd and 3rd half-whorls is found in the genera mentioned above as well as in *Promicroceras*. The further change about the 6th half-whorl is present in several other ammonites ; and in some of those in which it occurs, apart from *Promicroceras*, there is also a change about the 4th half-whorl. It is significant, therefore, that the change at the 2nd–3rd half-whorl and about the 6th half-whorl together are found typically in all the species of *Promicroceras* which have been studied.

While these early changes in growth rates are apparently consistent in these species, after the 6th half-whorl there is more variation. In some there is little further change of growth gradient of median whorl height as in *P. marstonense* : in others there is a decrease followed by an increase in rate of growth somewhere between the 8th and 11th half-whorls. The differences depend on the number of half-whorls before these changes begin and the number of half-whorls before the reverse change takes place. They thus occur at rather different diameters. It is possible that the first change, the decrease of growth rate of median whorl height, marks the onset of a new season's growth and it may be suggested that the different diameters at which these changes occur merely indicate the different sizes to which individuals in the different groups had grown in a certain number of seasons.

For convenience of description the various types of graph have been referred to four groups. It is possible that if some more specimens were available these types would seem to be more closely linked. Groups 1 and 2 include young *P. capricornoides*, and other forms including a young *Xipheroceras*, whereas the typical specimens of *P. pyritosum* occur in groups 3 and 4 ; this suggests that *P. pyritosum* may have been a quick growing form.

It may be of interest that the spiral angle corresponding to the general trend of the graphs of median whorl height between the 6th and 11th or 12th half-whorls, irrespective of the intermediate changes of gradient, was calculated for each specimen. It was found that the spiral angle corresponding to this general trend varies in groups 1 and 2 between 83° 11 and 84° 5′ and in groups 3 and 4 between 84° 14′ and 84° 26′.

In conclusion I should like to thank Professor Trueman for his continued help in the investigation of *Promicroceras*.

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"Gerontic" Structures in the Carboniferous Coral *Rotiphyllum costatum* (McCoy)

By R. G. S. Hudson

ZAPHRENTOID faunas occur in the Middle and Upper Viséan of Great Britain, but have not been adequately described and so are difficult to distinguish. Probably the most fossiliferous of such Upper Viséan faunas are those found in the D_{2-3} shales and grey limestones with chert which occur near the top of the Lower Carboniferous beds of Derbyshire. A characteristic form in these faunas is that usually assigned to *Zaphrentis costata* (McCoy), a species imperfectly known and inadequately described. In 1937 I collected such forms from Cawdor Quarry, Matlock Bridge, Derbyshire, with the intention of identifying and redescribing the species. Since then sections have been made from the lectotype: these sections, however, are imperfect and a specific description based on them by Hill (1940, p. 137) [1] is necessarily incomplete. The specimens from Cawdor include one which is similar to *Z. costata* but which shows successive contractions of the corallum and a change from straight to waved and corrugated major septa, a phenomenon possibly due to "gerontism".

In this paper I identify specimens from Cawdor Quarry as *Z. costata* (McCoy), redescribe the species, allocate it to the genus *Rotiphyllum* Hudson (1942, p. 257), and discuss the significance of certain structural modifications in a particular specimen.

Rotiphyllum costatum (McCoy). Text-figure 1*a–d*.

Cyathaxonia costata McCoy, 1849, p. 6; 1851*b* (1852), p. 109, pl. 3C, fig. 2*a*.
Zaphrentis costata (McCoy). Hudson & Platt, 1927, p. 39; Hill, 1940, p. 137, pl. vii, fig. 63.

Lectotype.—Specimen A 2392, Sedgwick Museum, Cambridge, from Lower Carboniferous, Derbyshire. Figured McCoy, 1851, pl. 3C, fig. 2*a*, and Hill, 1940, pl. vii, fig. 63.

Paratype (former syntype).—Specimen A 2391, Sedgwick Museum, from Lower Carboniferous, Derbyshire. Figured McCoy, 1851, pl. 3C, fig. 2.

Plesiotypes.—Transverse sections R 34601*a–j*; specimen R 34602 and trans. sects. R 34602*a–d*; specimens R 34604–8; trans. and long. sects. R 34610*a–e*, British Museum (Nat. Hist.). All from *R. costatum* beds, Cawdor Quarry, Matlock Bridge, Derbyshire. Zone D_{2-3}, Upper Viséan.[1] R 34610*a–b*, *d–e* figured this paper as text-figs. 1*a–d*; R 34601*a–d*, *f–j* as text-figs. 2*a–c* and 3*a–f*.

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[1] References are to papers listed (pp. 37–52) in "The Carboniferous rugose corals of Scotland", by Dorothy Hill, *Mon. Pal. Soc.*, London, 1938–1941. Papers which are referred to but which are not in that bibliography are listed at the end of this paper.

[1] About 100 feet of beds occur above the lava which is seen in a trench in the floor of Cawdor Quarry. The lower 66 feet are mainly light-coloured limestones without chert; the upper 36 feet are shales and dark-grey limestones with chert. The lower beds, which are sparsely fossiliferous, contain crinoids, brachiopods (mainly of *Productus* (*Gigantella*) *maximus* type) and occasional corals: the top 1½ feet are darker in colour and mottled with pseudobreccia: the upper

Description.[1]—The lectotype is straight and ceratoid, about 29 mm. long, but is so crushed that it is not possible to measure its distal diameter. The transverse section (Hill, 1940, pl. vii, fig. 63), cut from just below the calyx, is 15 mm. by 10 mm. and shows twenty-six straight, wedge-shaped major septa thinning axially. Part of the peripheral thickening of the septa is due to the lining of their sides by the continuation of the tabulae with the result that their thickness decreases suddenly at the junction of tabulae and septa. The counter septum is slightly thicker and longer and the cardinal septum slightly thinner and shorter than the other major septa. The minor septa are stumpy and embedded in the lining of the epitheca. Fossulae are indistinguishable from other interseptal loculi. The septa do not reach the septal axis but join short of it to form a small incomplete stereotheca whose shape has been destroyed by the crushing. The section figured as text-fig. 1*d* is from the same growth-stage of an uncrushed specimen : here the axial hollow is continuous with the counter pseudofossulae and bisected by the elongated counter septum.[2] In some specimens the septa have not all equally retreated from the axis so that the axis structure is a cellular stereocolumn as in text-fig. 3*b–f*. In most cases the largest break in the stereocolumn is on one or both sides of the counter septum.

The tabulae are mainly complete, conical, and slightly curved, forming an angle of about 45° to the vertical. In the cardinal fossulae they form a sigmoidal curve between stereocolumn and epitheca, their middle parts being approximately vertical.

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surface is irregular, slightly potholed, and has a thin coal, about ⅛ in. thick, in pockets on it. The upper beds are very fossiliferous and at one level contain an abundant Zaphrentoid fauna. They may be divided into two, a lower 14 feet of grey limestone with chert and shale-partings and an upper 22 feet of shale with a 4 ft. bed of limestone (calcite-mudstone) at the base and a 3 ft. grey limestone with many small productids near the top. The 14 feet of grey limestones with chert are the *R. costatum* beds. Fossils are mainly in the shale partings and especially in those in the 2 feet of limestone 8 feet from the bottom of the series. Some of the specimens collected are deposited in the British Museum (Nat. Hist.) and catalogued under the numbers R 34601–25. The corals in the fauna include :—

Amplexus sp. cf. *Allotriophyllum cuspidum* (Thomson)
Amplexoid Zaphrentoids
Cladochonus spp.
Cyathaxonia cornu—rushianum group
Emmonsia parasitica (Phillips)
Rhopalolasma sp.
Rotiphyllum costatum (McCoy)
R. aff. *rushianum* (Vaughan)
"*Zaphrentis*" *derbiense* Lewis
"*Z.*" *enniskilleni* var. towards *Z. curvulena* Thomson
Z. enniskilleni group cf. *Z.* sp. Wilmore 1910
"*Z.*" sp. cf. *Z. densa* Vaughan 1908 *non* Carruthers 1908

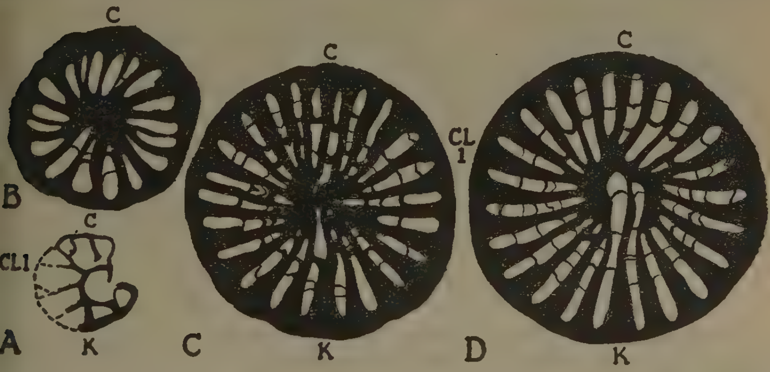
Many of the above stratigraphical details and many of the fossils were kindly obtained for me by W. Davies, of the University of Sheffield. The general sequence in the quarry was shown by me to a party of the British Association during the Nottingham meeting.

[1] The septal terminology used in these descriptions is that defined by me in a previous paper (Hudson, 1936).

[2] If the orientation of a transverse section at the late ephebic stage, such as text-fig. 1*d*, is reversed so that the cardinal septum is considered the counter septum and vice versa the septal plan is very similar to that of *Zaphrentites constricta* (Carruthers). Carruthers (1910, p. 352) identified the paratype (former syntype) of *Z. costata* McCoy as *Z. constricta* ; this may be a wrong identification due to wrong orientation : I have, however, not seen the specimen.

Ontogeny.—The transitional growth-stage (text-fig. 1*a*) is similar to that of other members of the *Fasciculophyllum omaliusi* gens. The neanic growth-stage may be divided into an early zaphrentoid stage (text-fig. 1*b*) followed by a rotiphylloid stage with a stereocolumn, radial septa, and fossulae not very different from other interseptal loculi (text-figs. 1*c*, 2*b*, 2*c*, 3*a*). Later the stereocolumn is reduced, becomes cellular, and the various fossulae extend into it (text-fig. 3*b–d*): finally the partial stereotheca of the ephebic stage replaces the stereocolumn (text-fig. 1*d*).

Remarks.—The concave curvature, in the neanic stage, of the septa o the cardinal, the tendency towards counter pseudofossulae, and, where ne corallum is slightly curved, the position of the cardinal on the convex ide place the species *costatum* in the *F. omaliusi* gens while the evenly paced, radial, major septa meeting axially to form a stereocolumn place t in the genus *Rotiphyllum*.



EXT-FIG. 1.—Transverse sections of *Rotiphyllum costatum* (McCoy) from *R. costatum* beds, Cawdor Quarry, Matlock Bridge, Derbyshire. Viséan, Zone D_{2-3}. A, transitional growth-stage, B.M. R34610a, × 6·6 (1·9 mm. diam., 3 KL, 3 CL). The right side of the corallite has been impressed by some other object and is thus distorted; the right cardinal and counter laterals are thus retarded. The left side of the corallite, destroyed when making the thin section, has been restored. B, neanic stage, B.M. R34610b, × 6·6 (3·5 mm. diam., 4 KL, 4 CL). C, late neanic growth-stage, B.M. R34610d, × 4·4 (8 mm. diam., 6 KL, 5 CL). D, late ephebic growth-stage, B.M. R34610e, × 4·4 (8·5 mm. diam., 6 KL, 5 CL). K, counter septum; C, cardinal septum; CL1, first cardinal-lateral septum.

A closely related form (B.M. R 34602 and trs. sects. *a–d*), probably structurally earlier member of the same species plexus, has a more hopaloid counter septum and a larger stereocolumn which persists hroughout the ephebic stage; this form is similar to *F. densum* Carruthers) from which it is distinguished by its straight, wedge-shaped epta and by the earlier occurrence in its ontogeny of the rotiphylloid eptal plan.

R. charlestonense (Thomson) and *R. granulate* (Thomson) both differ rom *R. costatum* by their more slender septa and by the penetration of he cardinal fossulae into the stereocolumn. The axial structure in both of Thomson's species is wider than in *R. costatum* (see Hill, 1940, p. 139, and Hudson and Fox, 1943, p. 108). *R. costatum* is distinguished from *R. rushianum* (Vaughan) mainly by the absence of marked cardinal fossulae, by the presence of counter pseudofossulae, and by wedge-shaped as opposed to peripherally nodose septa (compare B.M. R 34603 and transverse sections *a–d* from Cawdor Quarry).

GERONTIC STRUCTURES

One specimen (B.M. R 34601) of *Rotiphyllum* aff. *costatum* from Cawdor, about 30 mm. long, was about half ceratoid and the rest approximately cylindrical. As the cylindrical part showed some reduction in diameter the coral was completely sectioned. The sections are figured as follows: B.M. R 34601*a–c*, text-fig. 2*a–c*; R 34601*d*, text-fig. 3*a*; R 34601*e*, not figured; R 34601*f–j*, text-fig. 3*b–f*. The first four sections (text-figs. 2*a–c*, 3*a*) are from the neanic growth stage and show normal development except that there is slight and partial calyx contraction (text-fig. 2*c*), and the septa throughout tend to be slightly waved. The corallum at the end of this stage is 10 mm. wide, has twenty-two septa and a small but definite stereocolumn penetrated by the counter pseudofossulae (text-fig. 3*a*): this stage is identified as the late neanic one of *R. costatum*. The next six sections (text-fig. 3*b–f* and unfigured section) are from the cylindrical part of the corallum. Here there are two periods of abrupt contraction and partial recovery of the corallum: the beginning of the first is shown in text-fig. 3*b* and the end in text-fig. 3*c*; the beginning of the second is shown in text-fig. 3*d* and its end in text-fig. 3*f*. The unfigured section between text-fig. 3*a* and *b*, and a section, unfortunately destroyed, between text-fig. 3*c* and *d* each indicate the following contraction by a peripheral stereozone formed by the thickened bases of the major septa and the buried minor septa. The first contraction is from 12·5 mm. to 9·5 mm. (text-fig. 3*c*), and the second from 10·5 mm. to 7·5 mm. (text-fig. 3*f*). The process of corallum contraction in the Zaphrentoids starts with the formation of small interseptal loculi within the peripheral stereozone. The inner side of each loculus is lined by a thin dark layer: these layers, as the septa thin and the new interseptal loculi increase in size, join and form the new epitheca. The opening of these new interseptal loculi in the stereozone reveals the minor septa on the inner side of the old epitheca; they do not develop on the inside of the new epitheca until much later.

The section of text-fig. 3*b* and the previous unfigured section show that there was at this stage considerable disturbance to the normal growth of the corallum on the right-hand side [1] of the corallum between KL5 and CL1. The interseptal loculus between RKL6 and RCL1 is eliminated by these two septa joining, starting axially. The process is not quite complete in text-fig. 3*b* where there is a small peripheral part of RKL6 left. This septum never reappears so that subsequent sections show twenty-one septa against the twenty-two of the earlier sections. Moreover the interseptal loculi between RKL5, RKL6, and RCL1 are reduced by local corallum contraction effected by the setting up of a new epitheca within the old, not by the splitting of the peripheral stereozone but by the introduction of a vertical plate, probably an upturned tabula, stretching from septum to septum. These local disturbances in the normal structure were probably due to some adverse but local condition. It is of interest to note that on the external surface of the corallum opposite the disturbed part there is an encrusting polyzoan zoarium. Encrusting bryozoa attached to Zaphrentoid corals are rare presumably because

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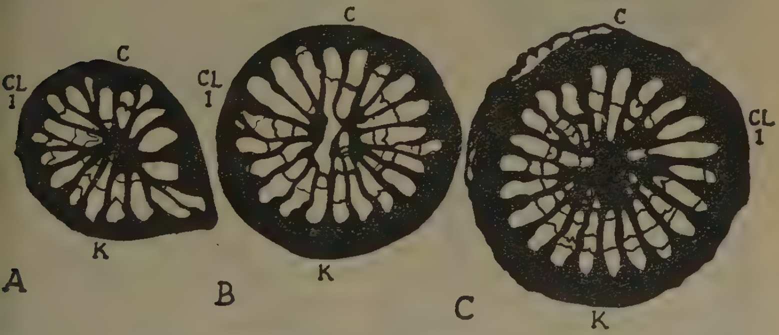
[1] The figures 2*a–c*, 3*a–d*, *f* are reversed so that the right-hand side of the corallum viewed from above is to the left of the figure. Figure 3*e* is correctly orientated. All references in the paper to right or left apply to the figures and not to the sections.



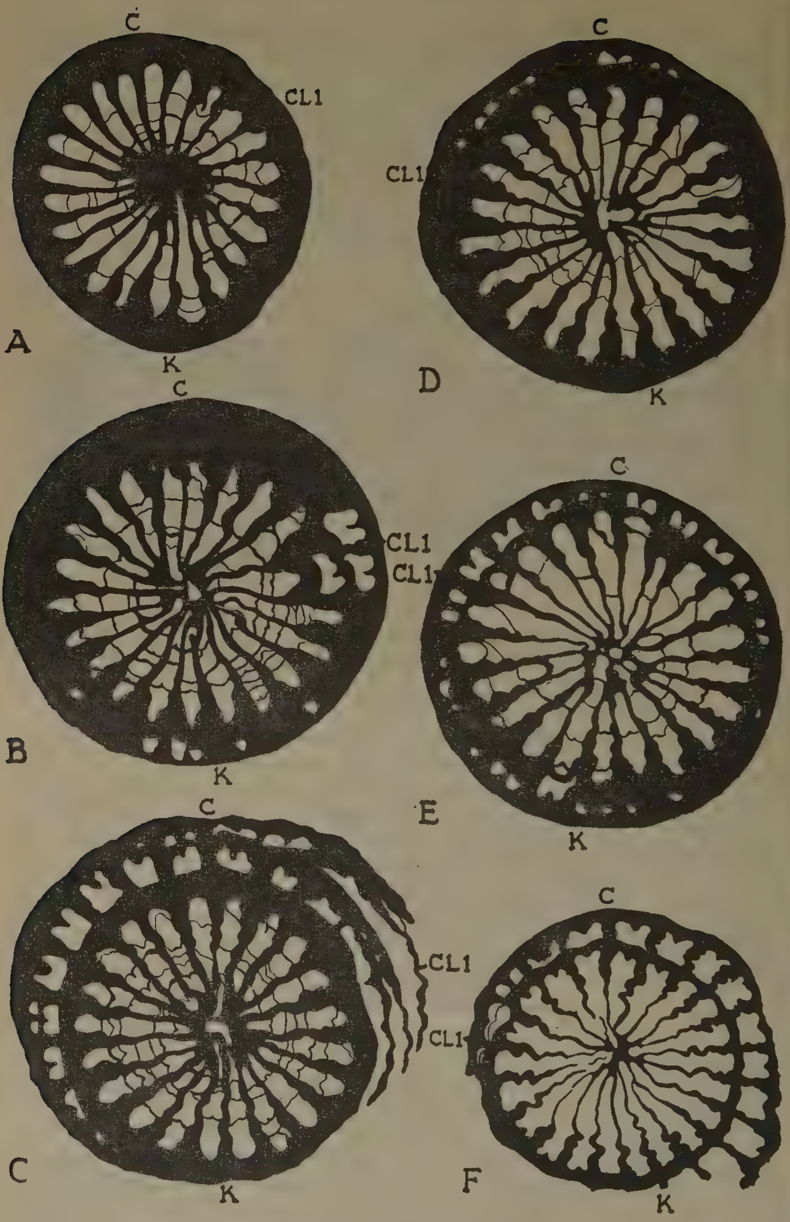
TEXT-FIG. 2.—Transverse sections (B.M. R34601a–c) from neanic growth-stage of *Rotiphyllum* aff. *costatum* (McCoy). All × 4·4 ; from same locality as specimens figured text-fig. 1. A, 6·7 mm. diam., 5 KL, 4 CL ; B, 7 mm. diam., 6 KL, 4 CL ; C, 8·5 mm. diam., 6 KL, 4 CL.

the corallum, except for a small part of the distal end, was buried in the mud of the sea floor. In this specimen the polyzoan zoarium was probably attached close to the calicular edge and it seems probable that the local contraction of the corallum and the consequent elimination of a septum s the expression of the reaction of the coral polyp to the attached zoarium.

The main interest of the sections under discussion is, however, the corrugation of the septa, a feature which occurs in the pre-Carboniferous rugose corals but not, as far as I am aware, in those of the Carboniferous. The waving of the septa starts in the late neanic stage (text-fig. 3*a*), and persists throughout the remainder of the corallum, increasing in ntensity so that the septa become sharply corrugated towards the end of growth (text-fig. 3*f*). The corrugations are parallel with the growth direction of the septum ; the median line of the septum is more sharply folded than the septum and, at times, the surfaces of the septum are not parallel so that the septum is nodose rather than corrugated.

The stereocolumn is very loosely constructed in the cylindrical part of he corallum and in the section just below the calyx (text-fig. 3*f*) is little nore than a structure linking the axial ends of the various groups of epta : it never becomes a complete or partial stereotheca such as characterizes the late ephebic growth-stage of the species.

The departure of this specimen from the normal structure of R. *costatum* thus includes the reduction by abrupt stages of the diameter f the corallum from 12 mm. to 8 mm., the reduction in the diameter



Text-fig. 3.—Transverse sections from (A) late neanic and (B–F) early ephebic growth-stage of *Rotiphyllum* aff. *costatum* (McCoy) showing contraction of corallum, and gerontic septa and stereocolumn; sections from same specimen as those of text-fig. 2. All × 4·4. A, B.M. R34601d, 6 KL, 4 CL; B–F, B.M. R34601f–j, 6 or 5 KL, 4 CL.

and compactness of the stereocolumn, and a change from approximately straight to corrugated major septa. These changes are probably the components of one variation, though it is not possible to say which is the fundamental factor in it.[1] The variation is not an integral part of that which both links and divides the members of the *R. costatum* plexus nor, indeed, is it known in other members of the *F. omaliusi* gens. It therefore has no phylogenetic significance and is individual rather than specific variation. Since the contraction of the corallum is a feature of the variation it is, I think, legitimate to assume that the factors inducing it were adverse ones. It is not likely that the variation is the impression of external conditions on the organism for, otherwise, other individuals of the species in the same locality would have been affected though it is possible that the presence of the encrusting organism mentioned above adversely affected the polyp in addition to causing local disturbance of its structure.

Individual variation in the rugose coral *Heliophyllum halli* Edwards & Haime has been discussed by Wells (1937). Among the factors inducing such variation he includes gerontism and considers it to be expressed by *H. halli* forma *degener* which is characterized by the gradual contraction of the corallum near the calyx.

In an earlier paper (Hudson and Anderson, 1928, p. 339), I considered that those individuals of *Hettonia fallax* in which there was continued absence of the axial column were gerontic forms, the controlling factor being a reduction in vitality. The occurrence of such a factor seems the most probable reason for the abnormal structures in the corallum of *R.* aff. *costatum* discussed above and now considered to be a gerontic form of the species. The successive and abrupt contractions of the corallum in that specimen are similar to those noted in many other corals and termed " rejuvenescence ". Such contractions often, though not always, follow some simplification in the internal structure and are usually followed by a return of the structure of that of the normal ephebic corallum and a recovery of its diameter. In such a case the " gerontism " is a temporary phase probably due to other causes.

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[1] It is possible that a corrugated septum is a mechanical solution to the problem of fitting a lengthy septum into a corallum of reduced radius and that the fundamental factor in the variation is the reduction in diameter of the corallum.

The Cleveland Axis

By R. H. Rastall

Among the most notable features of the geology of Yorkshire are two parallel structures known as the Cleveland and Market Weighton anticlines. Although they are parallel and not far distant, it has often been pointed out, and especially by Kendall and Lamplugh that these structures differ in almost every possible way. The Market Weighton axis has now no topographical expression at the surface, whereas the Cleveland axis forms the watershed of one of the most clearly developed river-systems of the country. The first and most obvious meaning of this is that the Cleveland axis moved during the Tertiary, while the Market Weighton axis did not. But the real fundamental difference goes much further back than that.

Little is known of the history of the Market Weighton region earlier than Jurassic times. Almost the only information we have is derived from a deep bore in search of coal, which was abandoned at 3,100 feet, still in the Permian, with rock salt and anhydrite, giving a minimum thickness of 2,400 feet for the Permian, which is much greater than anything known in Cleveland.

On the other hand it is clear that the Cleveland axis is situated exactly on the line of the great pre-Permian anticline which separates the Yorkshire and Durham coalfields. As the Permian here rests on everything down to Lower Carboniferous several thousand feet of strata have been removed from this anticline in late Carboniferous and pre-Permian times. The whole area must have been levelled down before the end of the Trias, since so far as is known the Rhaetic passes over the axis in its usual development, about 30 or 40 feet thick and of normal facies, with its limited fauna. On this follows the Jurassic system, nearly all marine and very thick, up to and including at any rate part of the Kimmeridgian. As will be shown later the succession is not quite complete and uninterrupted, but it shows a strong contrast to the Market Weighton area, where as Kendall showed long ago, the Lias is very thin and the rest of the Jurassic is absent altogether.

The difference between these two structures has played a large part in several important discussions of folding in general, notably in a Presidential Address by Lamplugh to the Geological Society of London in 1919. Here it was shown that there is a close resemblance between Cleveland and the Weald. In the last named there is a deep syncline of Jurassic rocks under the anticline of Cretaceous rocks, which forms so marked a feature of Southern England. Lamplugh also showed that the Jurassic sequence under Cleveland is thick, and later he elaborated this theme, with details, in another address to the Yorkshire Geological Society, wherein he proved a differential depression of about 2,500 feet during the deposition of the Jurassic. No later rocks exist over the region, but the Tertiary anticline is obvious, with a minor syncline in North Cleveland. This point has been taken up by later writers, with stress on the analogy between Cleveland and the Weald, and specially by Arkell in a communication to the XVIth International Geological Congress at Washington, 1933. In this the following passage occurs with reference to Mesozoic and Kainozoic folding in England.

> " Where the Jurassic rocks can be seen in the English examples, as in the Cleveland and Islip anticlines, they are folded, but do not thin out or show change of facies, unconformities, pebble beds, or non-sequences as they pass over the axis. There is thus no evidence of uplift during the Mesozoic era."

This statement may be true of the Islip axis, of which the writer has no personal knowledge, but as regards the Cleveland axis this sweeping generalization requires a good deal of qualification, as in point of fact some of the features here said to be absent are rather strikingly shown in the area, although it is true that the Jurassic system is thick and must have been laid down in an area undergoing general depression. But there certainly are notable non-sequences and changes of facies, as well as wide variations of thickness, and as will be shown later, even a quite conspicuous unconformity actually on the central line of the axis.

Moreover in Yorkshire the Portland, Purbeck, and Wealden are absent and there is a great overlap of the Upper Cretaceous, which in one place rests on the Lias : this is not seen however in Cleveland, where no rocks later than the Oxfordian now survive, and there is nothing to show that they were ever deposited.

In order to prove the points here raised it will be necessary to discuss the geology of the region in some detail.

Although a strict definition of Cleveland is not essential for our present purpose, it may be mentioned that the name is now often used in a much wider sense than formerly, especially by geological writers. It is often apparently meant to include the whole of the hilly country north of the Vale of Pickering, which is certainly historically incorrect. In the writer's younger days it was always understood that the southern boundary of Cleveland was the Esk-Derwent watershed as far east as the Murk Esk, then the Murk Esk itself and the eastern limits of the parishes of Egton and Lythe to the sea at Eastrow. This is fully borne out by the map in Ord's *History of Cleveland* (1846). This definition leads to the curious paradox that only half of the Cleveland anticline is in Cleveland, since the Esk-Derwent watershed is the crest of the anticlinal fold.

The axis of elevation reaches its highest point on Dromonby Bank near the head of Bilsdale and from thence pitches gently both east and west. The eastward pitch is fairly regular about as far as Goathland, but east of this point the structure is interrupted by a transverse syncline, followed by a very irregular system of anticlines and synclines, with one well-developed dome around Aislaby, recently bored for oil, without success. There is a slight interruption at the Whitby fault and at Robin Hood's Bay another elevation may be half of a dome cut off by the coast. This structure has been worked out with the Dogger as a marker, and a contour map of the eastern part has been published by Lees and Cox. Unpublished work on the same formation shows that the Dogger attains its highest point, about 1,350 feet O.D. on Dromonby Bank, while against the Whitby fault it is probably about −300 O.D., slightly less deep than shown by Lees and Cox in their map. A very similar map was published the same year by Versey for the Grey Limestone Series.

In Cleveland proper faulting is insignificant except for the Upsall fault in the northern syncline, across the mining field. There are two fairly large N.N.W.–S.S.E. faults at Whitby and at Peak, and an important one along the north side of the Vale of Pickering, which determines the northern limit of the Kimmeridge Clay. The age of the faulting is uncertain, except that the first movement of the Peak fault was earlier than some of the Aalenian.

The principal object of this paper is to show that the Jurassic succession in Cleveland is not so uniform and free from interruptions as is implied in the quotation from Arkell already given. In order to do this it will be necessary to give a short general description of each of the series as they are developed locally. The great unconformity between the Jurassic and Cretaceous in the East Riding is irrelevant and will not be discussed, nor will the details of the Market Weighton region.

The Lias.—It has long been recognized that the Lias is thick in North Yorkshire and, as emphasized by Lamplugh in 1921, that it thins towards the west as well as towards the south. The actual figures in some recent bores, though known to the writer, cannot be given in the absence of express permission, but they fully bear out this statement. The greatest thickness is probably under the sea, east of Robin Hood's Bay, where the base is not seen. In the Coal Commission Report of 1905 Kendall gave a thickness of 1,268 feet for this locality, so it is safe to say that the maximum thickness is at least 1,300 feet, and probably more. The Lias may be briefly summarized as a period of continuous marine deposition up to and including the bifrons zone. Consequently it is only the character of the highest part of the series that concerns us here. The serpentinum horizon is very oily, and the Alum Shale (bifrons zone) may be shortly described as a euxinic phase, giving rise to black shales with much sulphide, the foundation of the alum industry, now long extinct.

But after this things began to happen. Rocks with the variabilis-lilli fauna have a very limited distribution indeed, being only known in place for certain at Peak, while one ammonite has been found in flood debris inland. The striatulum and dispansum zones, till lately only known at Peak, have now been found in a basin of at least 50 square miles some 20 miles west of Peak in the Danby-Rosedale area. All this cannot now be discussed in detail : it must suffice to say that both at Peak on the coast and in the Western Dales there is indisputable evidence of a period of highly disturbed conditions in Yeovilian and Aalenian times, with extensive erosion and numerous stratigraphical non-sequences. *Nowhere is there an uninterrupted transition from the Lias to the Middle Jurassic.*

The last marine strata of the region are in the murchisonae zone. After this follows the long episode of the formation of what has most unfortunately been called the Estuarine Series. These rocks never show any of the characteristics of estuarine deposits. On the contrary, they are typically deltaic, and in fact very like the Carboniferous Coal Measures, even to the existence of thin coal seams with seat earths and marine bands. There is also an extensive land flora of much the same ecological value as the Coal Measure plants, indicating fresh water swamps and a warm climate, while flooded rivers have given rise to an elaborate system of washouts at several horizons. At least one of the marine bands, the Ellerbeck Bed, shows a return of the peculiar conditions, whatever they were, that had led so often in the Lias to the precipitation of sideritic ironstones in the sea.

Although the facies of the deltaic beds is very constant, still there is a general variation from east to west. As long ago pointed out in Geological Survey memoirs the ratio of sandstone to shale increases from east to west, doubtless indicating that the source of the material is also to be sought in the west. Likewise the character of the marine bands is not constant. Towards the south the ferruginous Ellerbeck Bed passes into the Hydraulic Limestone of the Howardian Hills, while far to the west it has been worked as an ironstone (Ingleby Greenhow). Again, the Millepore Bed, which shows two distinct facies in the south, is not represented at all by marine strata in Cleveland, while on the other hand the Grey or Scarborough Limestone series is thicker and better developed in the north. It must be admitted that over a large part of the area there is not much limestone in this series, but in certain places where it shows marine fossils, it has been worked for lime, and locally enough ammonites have been found to assign it to the blagdeni zone. From this it follows that most of the Middle Jurassic of this area is Bajocian.

Over most of England this shallow water and often deltaic phase is brought to an end by the marine transgression of the Cornbrash. This is well known to be a diachronic formation. In South Yorkshire the Cornbrash is not represented at all, while in the Cleveland district only the upper division has been definitely located, and this with a peculiar fauna.

The local development of the Oxfordian is one of the most striking features of the geology of North Yorkshire. There could scarcely be a more striking example of the topographical differences due to a change of facies than the contrast between the flat plains of the Oxford Clay of the Midlands and the beautiful scenery produced by the thick Kellaways Sandstone in the stretch of country extending some 40 miles west from the coast north of Scarborough. This reaches its highest development in the great cliffs that bound the overflow channel of Newton Dale, through which the railway from Pickering to Whitby runs. The view over the great plateau formed by the same rock, looking northwards from Saltersgate, is most impressive. Here the thin shaly representative of the Upper Oxfordian merely forms a narrow strip of very wet ground at the foot of the great escarpment of the Lower Calcareous Grit. The Kellaways Sandstone also reappears as outliers in the middle of the syncline of North Cleveland, and this is the highest Jurassic rock now seen north of the Cleveland axis. The important point here is that the Oxfordian beds of Cleveland are developed as a shallow-water facies, with coarse sandstones up to 100 feet thick at the base, in strong contrast with the clays of the Midlands. In the east only the overlying 50 feet or so is clay or shale, and in the western escarpment there is no clay at all. It is clear that the shallow water facies extended right across the Cleveland axis.

In every elementary textbook it is made abundantly clear that the Corallian rocks of Yorkshire differ widely from those of the Midlands up to the Humber, while they closely resemble those of Dorset. It is hardly necessary to demonstrate at length that the Corallian facies of Yorkshire and Dorset was formed in shallower water than the thin Ampthill Clay of the Midlands, and the point is of less importance than might appear at first sight, since the most northerly outcrop of the Corallian north of Pickering, is several miles south of the central line of the Cleveland uplift, and there is nothing to show how far north it originally extended, although since the marine Kellaways facies is still to be seen in North Cleveland, the next overlying division probably once existed there also. But there is no proof that it did.

Still less is it possible to form any opinion as to the former extension of the Kimmeridgian, which is nowhere seen north of the latitude of Pickering, and it is now generally agreed that the Portland and Purbeck are not represented in the Speeton Clay. Hence for all practical purposes the latest formation concerned in the argument is the Oxfordian.

From a consideration of all the foregoing facts it is hardly too much to say that Arkell's statement is really only true for the Lias.

Some points concerning the whole succession will now be considered in rather more detail.

The total thickness of the New Red Sandstone in North Yorkshire is probably about 2,500 feet and at Market Weighton certainly over 3,000 feet. This is quite enough to smooth out all possible inequalities due to Armorican uplifts and to provide a good flat floor for the Rhaetic sea, which, as Lamplugh pointed out, can be taken as a very convenient baseline. Then there began in Cleveland a steady subsidence with a tilt to the east, which went on throughout the Lias. It is significant that the ironstones of the Middle Lias thicken westwards, as showing that this special material came from that direction. The Middle Lias is also more sandy than either the Lower or Upper divisions, and was therefore a period of shallower water. The euxinic phase of part of the Upper Lias indicates another deepening, with stagnant conditions.

The evidence already set out indicates a definite period of tectonic disturbance culminating about the end of the Yeovilian, with formation of structures having a N.–S. trend. This cannot be attributed to a renewal of movement along the E.–W. pre-Permian anticline, and it is difficult to find any other system to link it up with. There is no proof of any contemporary movement in the parallel Pennine axis, though there is some evidence of active denudation in the region to the west, derived from the petrography of the Yeovilian and Aalenian deposits of the region. The only known contemporary movements are the far distant early Cimmerian disturbances which began in the Balkan area in the Rhaetic and these have a Charnoid trend, and might conceivably even thus early be linked up with the Saxonian or late Cimmerian uplifts in Germany and Holland and thus with the Market Weighton axis at a much later date. But the discordance of strike makes any such correlation very improbable. At any rate the supposed Jurassic geosyncline of Cleveland had a bad jolt at that time.

In broad general terms it may be said that in Cleveland there is an unconformity between the Lias and the Middle Jurassic.

The fact that the truly marine period of the Lias was followed by the deposition of a miniature series of Coal Measures with three marine bands in a total thickness of only 600 or 700 feet implies a phase of very unstable conditions. Three marine bands indicate four uplifts, even if they were of small range, as was probably the case. In considering this series it is necessary to take into account two independent variables. First we have the great increase in the ratio of sandstone to shale from east to west, and second, the steady increase in total thickness from west to east: at first sight these facts seem somewhat contradictory. The figures for total thickness given by the Survey are :—Peak 677 feet, Rosedale 560 feet, Hambleton Hills north 390 feet. All these localities are very near the axial line. If the series is anything like complete it is difficult to reconcile the two variations. The most probable explanation seems to be that there are in the west actual gaps in the succession, in the landward part of the great delta, whereas in the east the deposition of the muddy facies was more continuous. In any case all the massive sandstones, such as Aislaby and Lowther Crag in Eskdale, are obviously lenticles, which cannot be traced far. The structure of the delta has been investigated by Black, who has shown that foreset beds are rare, and that important washouts occur at more than one horizon. All of this is clearly evidence of general instability and of rapid local variations. This is specially noticeable about the horizon of the Grey Limestone marine band, which varies greatly in lithological character from place to place, being in some localities hardly identifiable as a marine formation, whereas elsewhere it is quite definitely a limestone with oysters and ammonites. After another deltaic episode, apparently representing the Bathonian in about 200 feet, there was in North Yorkshire an incursion of the sea, giving rise to the Upper Cornbrash, which is well developed near Saltersgate.

The conclusion to be drawn from all this is that throughout this long period, equal to the whole Middle Jurassic with its innumerable ammonite zones, Cleveland was an area of vacillating physical conditions, with delta-filling in the west and deeper water to the east, but even there with shallow episodes and notable plant growth ; that is mud-flats rather than sand-banks, something like modern mangrove swamps. Moreover the details of the marine bands which have already been briefly sketched and need not here be repeated, show that there were notable changes of facies from north to south, as well as from east to west.

As already shown, the last formation which can be proved to have extended over Cleveland is the Oxfordian. Here again we have evidence of shallow water, in the east through the greater part of the period and in the west through all of it. But conditions seem to have been very uniform, although the Kellaways rock varies a good deal in thickness. But the maximum thickness, as given by Kendall for the neighbourhood of Scarborough is only about 135 feet, which is very much less than the possible minimum for the Oxfordian of the Midland Counties or Lincolnshire.

It therefore follows that the thickness of the Jurassic System or such part of it as is represented in North Yorkshire is over 2,000 feet, whereas at Market Weighton the Lias is very thin and the rest of the system absent altogether. Hence it is true that the northern Jurassic represents the filling of a sinking area, proceeding in such a manner that, at any rate after the Lias, the water was always kept shallow, and for a very long time the sea was almost entirely excluded. But it is not true that the various formations, especially the later ones, pass over the sunken area without interruptions or change of facies, as stated by Arkell. The most important conclusion therefore appears to be that a thick formation may have been laid down in a sinking area without giving in itself much evidence of continuous depression, unless it is compared with other areas where the conditions were different. This is in reality the main point brought out in the classic discussions by Kendall and Lamplugh.

REVIEWS

SOUTH AFRICAN SCENERY: A TEXTBOOK OF GEOMORPHOLOGY. By L. C. KING. pp. xxiv + 340, with 144 plates, 64 text-figures, and a map. Edinburgh and London: Oliver and Boyd, 1942. Price 25*s*.

The general scope of this book is more geological than is implied by its title. In fact the first seventeen chapters form an excellent short and condensed textbook of physical geology, based as far as possible on South African examples, while for glaciation and vulcanology recourse is had to Central Africa and New Zealand. Hence the ground is very well covered. The author's style is simple, clear, and easy, and though some technical terms not familiar to European geologists are here and there introduced, each is carefully defined, so that the meaning is obvious. Illustrations are very numerous and well chosen, the majority from the author's own photographs and some are very striking. It is most refreshing to find a book dealing with all the old standard geological phenomena with an entirely new set of examples, and also some subjects less familiar or altogether unknown. In the chapter on the arid cycle, although only nine pages long, there are several points of great interest, which will be touched on later.

It is hardly necessary to point out that for several reasons South Africa offers an unrivalled field for research in geomorphology: including perhaps above all the scarcity of vegetation in many areas, and the vast extent of bare rock often to be seen, as well as the great variety of structural types and the large scale of most things. There is also the advantage, as it seems to an unorthodox geologist like the present writer, of an immensely long stratigraphical succession largely uncomplicated by fossils. Above all there are no known Lower Palaeozoic rocks and no graptolites. It is difficult to see why some authors now assign the Waterberg System to the Cambrian. The author adopts this in his table, but expresses doubt in a note. The Waterberg correlates so nicely with red systems at the top of the Precambrian, e.g. Torridonian, in so many lands and it contains no fossils.

It seems to be now established that the Karroo System extends without notable break from Upper Carboniferous to Jurassic, which is awkward for the orthodox classification into Palaeozoic and Mesozoic. Although the Karroo System is conformable with the Cape System in the Worcester district, nevertheless the pre-Karroo (pre-Dwyka) erosion surface is one of the most important geomorphological features over an enormous area in Africa.

Owing to the dominance of Lyellian geology it seems to be almost tacitly assumed that the climate of north-western Europe, one might almost say of Britain, is the standard. In point of fact the humid type is the most widely spread, although it should not be forgotten that Walther long ago showed that one-fifth of the land area of the world is without drainage to the sea, and therefore of the arid type. Nevertheless there are extensive regions with a well-developed river system, where the general geological conditions tend to aridity. Obviously it is not all a question of rainfall : other important factors are involved. The geological effect of a given climate is a function of many independent variables, and of these temperature is of first importance. In the chilly climate of south-eastern England a rainfall of 20 inches, which in a hot country would be on the verge of aridity, is sufficient for the maintenance of a high degree of fertility. Another important factor is what may be called the concentration of the rainfall ; the question of whether it is evenly spread over the year or confined to a short and definite wet season.

Where such factors in combination work unfavourably, some very important problems arise. One of the most serious questions now facing mankind is that of soil erosion. Cultivation is an artificial process, leading to a disturbance of the equilibrium of nature, with the usual disastrous effects of such interference. As is clearly pointed out in the book under review, South Africa affords a striking example of this. Although there is a well-developed river system over much of the area, temperatures are high, vegetation is often scanty, and rainfall is markedly seasonal. It is a fact not usually made clear in textbooks of geology, that when it does rain in dry countries the falls are often very violent and concentrated, and some of the most striking effects of river transport that the present writer has seen were in South Africa, with the additional thrill of a train-journey of several miles through a flood, when it was by no means certain that the fire in the locomotive would not be drowned out.

In this book much stress is laid on the effects of this set of conditions, and many striking examples are given of erosion in the form of donga-formation, which has such disastrous effects in many cultivated areas. This may be described in more familiar language as the effect of cloud-bursts. It is also shown how in some instances what are usually regarded as palliative measures have only made things worse.

In the short chapter on the true arid cycle a comparison is made with the results obtained in America. Certain discrepancies are explained as being due to the fact that American deserts, with rainfalls up to 20 inches, are not really dry enough to produce the same effect as in Africa, where the rainfall may be 5 inches or less. It is interesting to note the definite statement that the Kalahari sands are red, while it is pointed out that red sands are also being formed in some areas on the east coast in a hot humid climate. It may be noted that " fused oxides of iron and manganese " is not a very happy description of desert varnish.

Three chapters are devoted to a detailed, often very detailed, description of the twenty-six geographical areas into which the area is divided. Naturally the Great Escarpment figures largely in these descriptions and it is stressed that " plateau and scarp " is the dominant feature of South African geomorphology. The last very short chapter is a discussion of the cycle concept. No references are given in the text, but there is a short bibliography of twenty-seven well-chosen items.

Much of the detail in the descriptive chapters can of course only be appreciated by those familiar with the country, but with this book and Dr. du Toit's splendid *Geology of South Africa*, due to the same publishers, students should find themselves well equipped to learn geology from their own country.

R. H. R.

SOME REFRACTORY MATERIALS IN NORTH-EASTERN ENGLAND. By R. G. CARRUTHERS and W. ANDERSON. Wartime Pamphlet No. 31. H.M. Geological Survey. pp. 19. 1943. Price 1*s*.

The area included in this pamphlet is almost exactly the basins of the Tyne and Wear, from Ferryhill in the south to Morpeth in the north, and from Alston to the east coast. This would perhaps be better described as northern rather than north-eastern England. The two geological systems concerned are the Carboniferous and the Permian and the products treated of are: moulding sands; silica sand; pencil ganister and quartzitic sandstone and silica rock. Of these the first group is the most important, including the basal sands of the Permian, which are very similar to the development in south Yorkshire, and various beds in the Millstone Grit. The Permian sands are not known to exist between Ferryhill and Castleford and Pontefract, where they are extensively worked. In Durham they are local and very variable in thickness, with a maximum of 168 feet at Sunderland. They seem to offer a promising field for development.

The most interesting geological point raised in the pamphlet refers to the " Rotted Grits " of the Millstone Grit series, which also afford good moulding sands. Several coarse felspathic grits of this series are deeply decomposed and this rotting is not due to recent weathering, as it is found in some bores as much as 200 feet underground. No explanation is offered of this strange phenomenon. This affords a moulding sand so well adapted for use in steel works that from one place it is carried as much as seven miles to the nearest railway and then via Newcastle to Sheffield. One would like to know something more about this weathering " of far older date ".

As for the other refractory products many details are given and the results of tests described, indicating some high quality sources of silica refractories, some unfortunately rather inaccessible.

R. H. R.

GEOLOGY OF THE FOREST OF DEAN COAL AND IRON-ORE FIELD. *Mem. Geol. Survey Great Britain.* By F. M. TROTTER, with contributions by W. C. C. ROSE. vi × 95, with 5 pls. H.M. Stationery Office, 1942. Price 6*s*.

This Memoir brings up to date available geological knowledge of a district which has been recognized as typical of coalfield basin structures for more than a hundred years. The Old Series 1 in. maps go back to 1845–1855, but exact information concerning the geometry of certain of its coal seams is even older, and was presented by Thomas Sopwith in *The Award of the Dean Forest Commission* of 1841.[1]

It was for this 1841 Commission that Sopwith produced his famous 5 ft. by 4 ft. sectional model on the scale of 10 in. = 1 mile. That model through the century, and especially during the reign of Professor T. McKenny Hughes, has served to show successive generations of Cambridge geologists how to see solid, and to appraise the usefulness of underground contours of geological maps. Its topography is faithful, and taken to pieces it records the then extent of coal workings in the Parkend, Churchway, and Coleford High Delph seams, and the expected location of underground contour lines at 100 ft. intervals extrapolated on each coal seam to the middle of the basin. It was fifty years before its time, and in many respects the new Memoir and its associated 6 in. maps demonstrate how shrewdly even at that time the maker of a model was able to approximate to the structural truth.

Seeking through this terse and factual record for new interpretations of Forest of Dean geology, coalfield geologists will be interested to note that only Upper Coal Measures, i.e. measures of the *Anthraconauta phillipsi* and higher zones all newer than the Mansfield Marine Band, are present. They are banked against a bevelled surface of Lower Carboniferous and Old Red Sandstone rocks with overlap and unconformity ever increasing towards the east. There are more red shales in measures of the Phillipsi zone below the Pennant Sandstone than in the Supra-Pennant Tenuis zone above. Folding and faulting troubled the Lower Avonian Limestones of Dean Forest quite a lot when Upper Avonian, Millstone Grit, and the Lower Coal Series of South Wales were being deposited ; but no evidence is adduced of differential sagging of the coalfield synclines during the intervals between successive standstills for the growth of coals. Hercynian movements which dished the coalfield basin followed lines only a little oblique to the N.–S. inter-Carboniferous ruling trend, but neither the new folds nor the faults which crossed them adopted or intensified displacements along the older structural lines. On this evidence the authors foresee " little likelihood " of unknown " coal seams lower than those found along the western outcrop at depth in the central part of the basin ". The form of the flat-bottomed Main Basin, now proved by mining the Coleford High Delph seam, is unusual. The 700 ft. high Staple-edge N. 15° E. trending monocline which forms its eastern flank is as sudden as any Coal Measure structure in the country.

Concerning the Carboniferous Limestone Series and Iron-ore deposits, the new Memoir is supplementary to Volume X of the Special Reports on Mineral Resources, prepared by Sir Franklin Sibly during the 1914–18 War, and revised by W. Lloyd in 1927. For the Limestone it adopts the zonal classification of Sibly and Reynolds, 1937, with amplification and some correction of fossil lists by Dr. Stubblefield. The Drybrook Sandstone is not younger than S_2.

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[1] Sopwith, T., 1841. The award of the Dean Forest Commissioners as to the Coal and the Iron Mines in Her Majesty's Forest of Dean, and the Rules and Regulations for working the same with preliminary observations and an explanation of a series of sixteen engraved plans of the Forest of Dean Mines. London.

Following the extraction of about five million tons of ore in fifty years, haematite mining in and about Dean Forest has been a dying industry since the beginning of this century. The authors' emphatic conclusion " that the [mineralizing] solutions came from above appears to be beyond reasonable doubt " will not revive it, nor can it encourage deep prospecting underneath the coalfield. These geologists with experience of Cumberland conditions have recognized that in South Wales the Trias is banked against steep cliffs so that " the Keuper was either not deposited over the Forest of Dean, or was deposited as a very thin bed from which it would be impossible to derive large bodies of haematite ". For the supply of iron solutions they therefore look, as did Professor O. T. Jones in 1931, to the pre-Trias weathered surface of Hercynian mountains. Ferruginous laterite is a common type of regolith in semitropical monsoon climates ; but how, from pyrite and ferrous salts in Coal Measures or other Carboniferous rocks, soluble iron salts can be brought down to cracks and fissures below the land surface of the unconformity, or (if brought down) how they could react with and replace by monohydrate haematite (almost free from phosphorus, sulphur and alumina) not only crazy limestone and sandy dolomite of the Lower Carboniferous Series, but also the quartz grains of massive sandstones of the Pennant Coal Measures, does not yet appear. Sibly, in the Introduction to his 1919 Memoir, wrote the ore " occurs in masses of irregular shape which were formed by processes of metasomatic replacement, that took place long after the consolidation of the enclosing rock ", and in Chapter 9 concluded " the process of ore formation obviously involved a permeation so complete that the constituent grains of the rock could be attacked from the minute interstitial spaces ". By 1943 we have made but little further progress in this argument.

W. G. F.

ANNOUNCEMENT

CLOUGH MEMORIAL RESEARCH FUND

This fund was instituted in 1935 for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Cumberland, Durham, Westmorland, and Yorkshire. Under the terms of the administration of the fund a sum of approximately £30 is available annually.

Applications for grants for the period 1st April, 1943, to 31st March, 1944, are invited. Applications should state :—

1. The nature of the research to be undertaken.
2. The amount of grant desired.
3. The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavation of critical sections, etc.
4. Whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Research Fund Committee, Edinburgh Geological Society, Synod Hall, Edinburgh, not later than 1st March, 1943.

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On Fluorite and Other Minerals in Lower Permian Rocks of South Durham [1]

By A. Fowler, H.M. Geological Survey

During the past two years several core-borings have been put down in South Durham in order to prove extensions of the Productive Coal Measures. In passing through the cover of Magnesian Limestone, here up to 300 feet thick, quite the most arresting feature was the presence of innumerable cavities of irregular distribution. These are especially characteristic of the Lower Limestones, and are of all sizes from tiny geodes almost completely infilled with calcite to gashes which cut deep into the heart of the 6 in. core. They are usually lined with calcite in a variety of forms; far more rarely there are other minerals among which fluorite and barytes seem to be the most abundant.

Whilst these minerals among others have been noted by other workers their manner of occurrence has not always been made clear. Apart from any other considerations, the frequent occurrence of fluorite in such quantity as has been noted in recent borings would merit more than passing comment, whilst in view of the importance of dolomite in the basic process of steel manufacture the presence of fluorite at once assumes something more than a mere academic interest.

As is well known fluorite, or fluorspar as it is more commonly known in the steel-smelting industry, is used as a flux in the basic process, being added to the " melt " at various stages to give a thinner and more fluid slag. And it is this very quality which makes its presence in dolomite so undesirable and one moreover well illustrated by the care taken, when feeding fluorite into the furnace, to avoid any contact with the dolomite " banks ". Conceivably, then, hearths and linings in which fluorite may be incorporated might from the very beginning of the furnaces' life be subject to corrosion from within as well as from without.[2]

Dolomite again is used in the daily " fettling "—repairing of hearths and banks after " tapping "—and in other ways, which need not be detailed here, and if contaminated by fluorite could scarcely be expected to give satisfactory results.

Barytes also occurs in the cavities of the dolomitic limestones more or less at the same levels as the fluorite but much more sparingly and being itself of a refractory nature probably has little or no deleterious effect, although of this we have no certain knowledge.

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[1] The information contained in this note was obtained during the course of official duties and is published by permission of the Director of the Geological Survey.

[2] This of course would be equally true for basic Bessemer converters.

To a much lesser extent other minerals are present; these include dolomite, ankerite, kaolinite, galena, sphalerite, pyrite, and limonite and will be mentioned more fully in the sequel.

The range and position of the fluorite and barytes infilling cavities and channels in the dolomitic beds of the Lower Limestones are given in the diagram (Text-fig. 1) [1] and although these minerals may occur outside this range—fluorite rarely—they are more or less concentrated within these limits. In the case of borings 3 and 4 the figures are only to be regarded as very approximate (possibly to within about 20 feet) as, through lack of core, the borers could not give a more definite depth. In borings 1 and 2 the range of the fluorite is much more accurately fixed; as, however, the fluorite levels seem to vary from place to place it is of no great moment whether or no the range is accurately defined; what does matter is that, in the cases in review, the mineral is concentrated in the beds locally quarried for dolomite for basic furnaces and converters.

GEOLOGY

As this note is concerned not so much with the rocks themselves as with the contained minerals only a very brief geological description need be given here.

Permian rocks covering the area of the map (inset Text-fig. 1), rest transgressively on Coal Measures and reach a thickness of just over 300 feet. The highest beds are mostly soft, earthy, creamy yellow to orange-coloured dolomites, sometimes false-bedded, and occasionally oolitic; on this account they may provisionally be included in the Middle Limestones. Although, broadly speaking, by reason of their soft powdery nature and more vivid colouring these upper beds contrast noticeably with the underlying tougher rocks of the Lower Limestones, nevertheless for one reason or another the two divisions are not easily separable and in this note the line between Middle and Lower Limestones is used rather to facilitate description, separating earthy limestones from more compact types, than as a strict divisional line.

The upper beds of the Lower Limestones in these borings are brownish and dolomitic, often partly grey and calcareous; the lower beds—"bluestones"—are mostly grey, highly calcareous, sometimes slightly crystalline but more often porcellanous or horny-textured. This division of the Lower Limestones into upper or dolomitic and lower or calcareous, although mainly true for these borings, is not widely applicable, as in the writer's opinion the dolomitization is secondary and dolomitic limestones may occur at any horizon. According to Woolacott, however, "the dolomitic beds of the Lower Limestone are chemical precipitates, and the calcareous beds represent conditions when the dolomitic precipitation was arrested (Woolacott, 1919, p. 486). Whatever the correct explanation it is in the dolomitic limestones that fluorite occurs in such marked quantity; moreover, it is just such limestones that are quarried for the supply of "shrunk dolomite" for the basic steel-smelting and refining furnaces of Middlesbrough, Tyneside, and the West of Scotland.

The Permian ends downwards with the remarkable deposit known as the Marl Slate, resting in turn on the Yellow Sands. These sands, here as elsewhere in Durham, are very sporadic in occurrence and as they are not present in any of the borings figured in the diagram are omitted from the index to the Permian strata.

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[1] Published by kind permission of K. M. Guthrie, Esq., Henry Stobart and Co., Ltd., Thrislington Colliery, West Cornforth, Ferryhill, co. Durham.

MODES OF OCCURRENCE OF FLUORITE, ETC.

In the course of this investigation a large number of specimens was examined by Dr. Phemister, Petrographer, H.M. Geological Survey; many of his findings are here quoted verbatim, within inverted commas.

Fluorite.—This mineral occurs in great variety, both as to form and colour. The crystals may be colourless and water-clear, pale-yellow, amber, violet or violet-brown, dark brown to black or cream coloured: in form they may be thin colourless tables, making rectangular contact with one another, or criss-crossing plates forming diamond-shaped cells or interspaces. Perhaps the most remarkable feature especially in borings 1 and 2 is the frequent occurrence of a somewhat lamellar type in which plates or septa of fluorite, usually dark brown but sometimes colourless, either meet at right angles or form "echeloned" parallel growths sometimes curved; these plates often showing stepped cubes stand out from the surrounding fluorite rather like a reticulate system of dykes in miniature. In some large crystal aggregates horizontal plates are seen meeting vertical rectangular plates, giving to the whole an octahedral outline: probably it is of this type that Dr. Phemister writes concerning a specimen from No. 1 bore, "the brown fluorite occurs occasionally as cubes, but is mainly developed as hollow octahedra or hopper crystals in which platy septa, parallel to the principal cubic planes, are prominent. The three-sided cups formed by these septa are occupied by small cubes of fluorite which are oriented in conformity with the walls of the cups." Many of these hopper crystals occur singly, but the close conjunction of a series might quite well produce the dyke-like system. Elsewhere in channels and cracks fluorite occurs as small cubes or may grow out from cavity walls "as large irregular crystals formed by a series of stepped cubes having a common orientation". In one irregular cavity nearly filled with fluorite of pale brown occasionally yellow colour the mineral "forms small diversely orientated cubes on free surfaces of the cavity but the main fluorite infilling shows simultaneous reflections from a large number of small faces indicating a general tendency to uniform crystallographic orientation". A microscopic examination of the enclosing rock of this sample suggests that the fluorite replaces the dolomite around the infilling. Dr. Phemister writes: "In thin section the rock is composed of minute (0·02 mm.) rhombs of dolomite coated with limonite or limonitic clay. Fluorite occurs in shapeless areas which appear to be due to replacement of the dolomite, since (1) dolomite is dispersed throughout the fluorite, and (2) the fluorite-rich areas pass into dolomite with fluorite mesostasis, the fluorite decreasing to vanishing proportions away from the fluorite-filled spaces. Some areas of fluorite are traversed by cloudy curving trails which possibly represent argillaceous matter residual from the dolomite which has been replaced by the fluorite."

In one sample fluorite ("isotropic, μ slightly greater than 1·432, well below 1·443") forms thin whitish plates, criss-crossing to give diamond or rhomboid cells or interspaces ; surmounting the plates and partially within the cells are small clear calcite crystals ("$\omega = 1{\cdot}658$") ; elsewhere " plates of fluorite seated on calcite project with free surfaces into the cavity. The plates are parallel to the cube face and show rectangular cleavages ". Platy fluorite occurs again in cavities " (1) free as if later than calcite, and (2) as V-shaped growths springing from the wall and almost completely enveloped in calcite ". Fluorite is also present as idiomorphic crystals in fracture and replacement veins.

In all four borings (1) a whitish powder and (2) a more compact, creamy, earthy, material were often found in and around cavity infillings. When, as so often happens, the creamy compact material is contiguous with crystalline fluorite, it is occasionally penetrated by the structural lines of the latter, suggesting that it might be a somewhat amorphous modification of the crystalline fluorite. On chemical test its identity as fluorite was proved. The same held good for some, but not all, of the white powdery materials. Accordingly Dr. Phemister carried out tests on different samples of white powders by immersion in oils of known refractive index. His findings were that in various cases the white powder was composed of : (1) fluorite, (2) mainly fluorite, (3) both fluorite and calcite, (4) equal proportions of fluorite and carbonate (calcite and dolomite), (5) mainly calcite, with some dolomite and probably ankerite, and (6) kaolinite and dickite.

Powdery material is rarely absent from the neighbourhood of cavity infillings ; it may be present as cavity linings upon which crystals grow, or as linings of cracks, in which it may surround crystals of fluorite, or again as a very fine dust mottling dolomite surfaces. When composed mainly of fluorite it is usually cream-coloured rather compact, and earthy, occasionally with closely packed cleavage planes, and sometimes it occurs as small earthy mounds with a faint radiate structure. These mounds are composed of fluorite crystals which have dominantly a thin prismatic habit and are interspersed with others of purplish fluorite in cubes and plates.

In the brownish dolomite of one bore were oval or circular infillings of horny texture, grey or greyish-brown in colour : they looked somewhat like anhydrite which some consider was an original constituent of the Magnesian Limestone. Nevertheless, chemical tests [1] showed they were composed of fluorite. This curious discovery affords a most unexpected addition to the diverse aspects of that mineral, and it is disturbing, for there is little distinction between the fluorite portions and the surrounding rock, so that this variety may be commoner than we suspect. Microscopic examination shows that " the rock is composed of finely granular fluorite which forms larger grains near cavities and develops idiomorphic faces on free surfaces. Single rhombs and clots of dolomite are scattered among the fluorite. There are a few small grains of quartz and ? feldspar ". Here as in the case already cited there seems to be a replacement of the dolomite-rock by the invading fluorite.

Barytes.—As compared with fluorite barytes is present in relatively small amounts ; it occurs usually in cavities lined with calcite and rarely it would seem, with fluorite, as few cases were noted where barytes and fluorite are actually in contact.

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[1] For these I have to thank Mr. S. I. Tomkeieff, Geology Dept., King's College, Newcastle-upon-Tyne.

Especially in the dolomitic beds of the Lower Limestones barytes is pinkish-white to pale-pink or flesh-coloured, and may be present as very slender rods, sometimes occurring singly, at other times in tufted groups. Under a pocket-lens these rods are seen to be rather rough-surfaced, somewhat segmented in appearance, and seemingly due to growth along the rods of tiny colourless crystals. A single rod may break at one end into several branches rather like the frayed ends of a wire or terminate in sheaves attached to the cavity wall. Stouter rods up to 0·25 inches thick vary in colour from white to pale pink or yellow, but in cross-section are always a decided pink, rather massive, showing under a hand-lens no trace of crystallinity : the outside surfaces of these also have a corrugated appearance due to the innumerable projecting small tabular crystals.

Barytes also occurs as small aggregates of pale flesh-coloured fibrous or curved platy crystals, as slender crystals occasionally enclosed within and as encrustations on calcite crystals, and as aggregates of thin criss-crossing plates (" biaxial, positive, $2V > 30°$, $\alpha > 1{\cdot}635$, $\gamma = 1{\cdot}649$ "). In one specimen a small narrow fan-shaped aggregate of a dull cream-coloured mineral enclosing a cube of fluorite " consisted of barytes with $\alpha = 1{\cdot}638$, $\gamma = 1{\cdot}648$, positive, 2E about 60° ".

About 25 feet below the fluorite-barytes levels in No. 1 bore barytes occurs plentifully in cavities as milky-white radiating groups or sheaves along with honey-coloured calcite ; the two minerals are grown one on another and seated on the cavity wall. Here, too, barytes is seen with calcite in crack-like, long narrow cavities. A few feet above, barytes, as " clear tablets, parallel to the basal plane ($\alpha = 1{\cdot}636$, positive, green barium flame) ", is found on calcite encrusting the surface of a grey calcareous limestone.

Calcite.—This mineral is by far the most common cavity infilling and occurs at all levels. In the earthy dolomites, geodes are, generally speaking, smaller than in the Lower Limestones and the calcite crystals, usually clear or colourless, are mostly closely packed scalenohedra, often capped by rhombohedral faces. Sometimes larger cavities are lined with a mammillated skin of calcite. A remarkable feature of the cavities in these earthy beds is that so far as one can see they often appear to be unconnected with fractures or veins.

In the Lower Limestones cavities, often quite large, are much more numerous, so that the rock is sometimes described by borers as " honeycomb limestone ". In the compact limestones the calcite varies very considerably in crystal form : mostly it is rhombohedral or some modification of the scalenohedron, but several types may occur in one cavity. The colour, especially in the dolomitic beds, varies from clear or colourless to milky-white, from a pale-yellow to a pronounced honey colour and may even be reddish. In the " bluestones " the mineral is usually glassy, often scalenohedral and up to an inch in length.

Calcite is also present as a white dust lining cavities or mottling limestone surfaces, and as the mineral infilling of the majority of cracks. Calcite veins are especially characteristic of the Lower Limestones forming conspicuous scars on core surfaces. The majority are joint and fracture-veins and the local thinning and swelling of the calcite infilling suggests local replacement of the walls. In one instance " replacement veins of calcite, coarse-grained and often with undulose extinction are of irregular thickness, contain limonitic aggregates left from the replaced dolomite and enwrap areas of dolomite projecting from the walls. Occasionally long crystals of barytes are enclosed and partially replaced by calcite. Fluorite occurs sparingly as small idiomorphic crystals ".

Galena, Pyrite, Sphalerite, and other Minerals.—Galena occurred in three out of the four borings figured in the diagram (Text-fig. 1), and in all cases at the base of the Permian, twice in the Marl Slate, and thirdly in bedded, finely striped limestone forming the bottom 10 feet of No. 4 bore. The mineral (in very small amounts) lines minute joints and more rarely is seen as thin films within the rock.

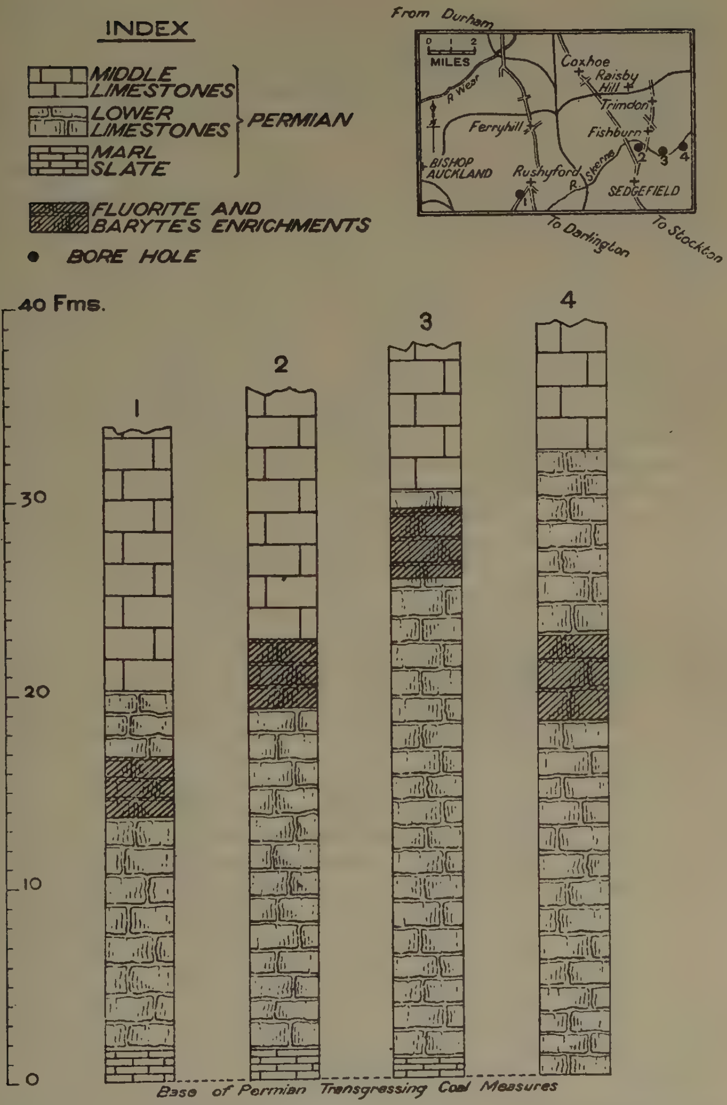
Pyrite has not so far been observed in the earthy dolomites, but is common enough in the Lower Limestone on the surfaces of calcite lining joints, as small grains on calcite crystals, as aggregates in " silty-seams ", or associated with calcite in veins. It also largely fills cavities in thin platy limestones often found towards the base of the Magnesian Limestone and is seldom absent from the Marl Slate.

Apart from the possibility of some of the crystals lining cavities being dolomite, the latter mineral was found once only when it occurred in a geode as a small flesh-coloured aggregate which Dr. Phemister found to be dolomite, uniaxial, negative, and with $\omega = 1{\cdot}682$.

Sphalerite.—In a boring at present proceeding near Whin Houses, about a mile east-south-east of No. 4 bore, a lozenge-shaped mineral, about 3 mm. long, was observed in highly calcareous limestone towards the base of the Permian. In the overlying 40 feet of rock a similar mineral occurred at intervals, mostly in joints, but quite often in the limestone. On examination by Dr. Phemister the mineral was found to be sphalerite, identified by its isotropism, cleavages, and high refractive index. Confirmation was got by chemical and blowpipe tests.

The mineral occurs either as well cleaved glassy crystals in the limestone or in joints as pale brown thin crystalline films showing good cleavages ; once it was got as pale yellow crystals on a dark silty parting in the limestone. When in joints it is more often than not accompanied by galena, while associated cavities contain water-clear barytes sometimes as prisms but usually as tabular or platy crystals. The association in the Whin Houses bore of sphalerite and galena in joints, and water-clear barytes in cavities is certainly remarkable. On close examination it is difficult to avoid the conclusion that the cavities are closely related to the joints, that they are solution cavities, and that in this instance at least they never contained, as some have claimed, either gypsum or anhydrite.

Whilst sphalerite was not observed in the fluorite-bearing dolomitic limestones of borings 1–4, it nevertheless may be present : the finding of this mineral is never fortuitous and in highly " browned " limestones it might easily be missed. At the same time it should be mentioned that although very carefully sought for no trace of fluorite has been found in the Whin Houses bore ; white platy barytes, however, in cavities and joints is fairly abundant in dolomitic limestones towards the top of the bore.



TEXT-FIG. 1.—Lower Permian Sequences in Recent Borings in South Durham.

Although by no means abundant crystals of a blackish mineral are occasionally observed on or between calcite crystals ; " this in a mounted crush is reddish fibrous and isotropic and is probably limonite," associated with it " there are very rare octagonal basal tablets of a greenish-yellow uniaxial mineral of very high refractive index and moderately low birefringence ". This according to Dr. Phemister may be scheelite or powellite.

Many particles of limonite were also found in a crush of fluorite which possessed an iridescent coating, and neighbouring calcite rhombs were similarly coated with limonite. There was, in addition, a brownish metallic and filiform encrustation on fluorite, the resemblance of which to mossy-copper proved deceptive on chemical test, iron being the main constituent. The mineral gave the yellow streak of limonite and when examined in a crush of oils proved to " be composed mainly of yellow and brown limonite which often shows a cellular dehydration structure and is sometimes in course of transformation to microspherulitic goethite ".

Occasionally a copper-coloured mineral was found encrusting calcite and fluorite ; it consists of scales which scrape off easily. " The mineral is of red-brown colour, rarely shows dichroism, is probably biaxial, and its scales are perpendicular to the acute bisectrix, the refractive indices are far above 1·84. A chemical test showed iron as an (or the) essential constituent. No other element was found although the quantity available for testing was very small. The mineral is therefore likely to be goethite but shows three sets of striations at 60° on some scales. It is suggested that the mineral is perhaps replacing siderite."

No copper was noticed except at Whin Houses (footnote p. 50) although malachite and chalcopyrite have been got in the " Limestone " at Raisby Hill and Garmondsway, and Dr. J. A. Smythe has shown me chalcopyrite from quarries in the basement limestones near Piercebridge, west of Darlington.

Order of Deposition.—The relationship between the various minerals is often difficult to interpret, and possibly not enough has so far been done to enable reasonably sound conclusions to be drawn.

It has been noted that fluorite, both of the crystalline and powdery varieties, forms the inner linings of calcite-filled cracks and again that calcite often forms on the fluorite-lined walls of cavities. This is the general and more usual condition, but exceptionally fluorite is found seated on calcite crystals whilst in one and the same cavity fluorite may occur on and subsequently be covered by calcite.

When, as rarely happens, barytes and fluorite are in contact the barytes is quite clearly the later mineral, whilst at the barytes-fluorite concentration levels, barytes is usually found as small aggregates on the faces of calcite crystals or as growths crystallizing in the interspaces. This relationship, however, is also subject to many exceptions, for as already mentioned calcite in veins or as crystals may enwrap barytes and so be the later mineral.

On occasion, then, there may be an initial deposit of calcite, but in the main fluorite seems to have been the first mineral formed in any great quantity, followed by calcite and finally barytes : the exception to this order suggests that calcite may have been formed contemporaneously with fluorite or barytes, or may have continued to be deposited for a longer period than these minerals. The occurrence of small calcite crystals as a later deposit on large calcite rhombs may indicate either that deposition was interrupted or that there is more than one generation of calcite. But whether an investigation into the habit of calcite would throw any light on its deposition is by no means clear. So far there seems little evidence to suggest any progressive sequence of crystal forms.

Whilst the quantities of ore minerals in the Permian are insignificant when compared with those of the Pennines, they are now seen to be much less so than once thought. This will be the better appreciated when it is remarked that, for example, in No. 1 bore, throughout a vertical distance of about 20 feet and within a core no more than 6 inches in diameter, cavities occur in almost every inch, sometimes with three or more to the inch and all bearing fluorite. It may be added that subsequent to the initial discovery Professor Fearnsides has noticed the mineral in one of the largest dolomite quarries of the district, observing that " vugs with fluorite are not uncommon " (*in litt.*, 18.11.41).

Dr. Dunham has discussed the insignificant quantities of ore minerals in Permian strata and has put forward several views as to their origin (Dunham, 1934, p. 712). Perhaps the chief reason for Dr. Dunham's suggestions is the notable absence of mineralized fissures in such Permian rocks as came under his notice, for he remarks that " In none of these cases was there any association of the ore minerals with fissures such as is the invariable rule in the Carboniferous rocks ". That apparent absence may well be deceptive : as far as concerns chalcopyrite and associated malachite at Raisby Hill, Mr. Saint, the manager, recalling one such occurrence, assures me that the minerals were in veins. Again, in his Marl-Slate paper, Lebour says, " At Garmondsway, as Mr. Atkinson stated, copper-ore occurs in the Magnesian Limestone, but in distinct veins of copper-pyrites, weathered externally into green carbonate of copper, not disseminated through the stone " (Lebour, 1903). Whether this was, as is more than likely, in the Garmondsway Moor shaft alongside Raisby Hill quarry (though separated by an important post-Permian dislocation, the Butterknowle Fault), or in some near-by exposure is not certain, but otherwise the evidence seems clear enough.

Finally there is the occurrence of barytes in joint-planes in the cores of the Whin Houses boring at present in progress about a mile east-south-east of No. 4 bore. Nor should it be forgotten that just such veinlet-fed geodes are a commonplace in the thicker of the Pennine limestones.

It is suggested, therefore, that the channels along which the solutions travelled to deposit their minerals in geodes or cavities are the innumerable cracks and joints which must have formed such a vast network throughout these Lower Limestones.

The dating of these Permian enrichments is an involved and difficult question on which as yet we have insufficient data.

A first and obvious idea would be that they belong to the Pennine mineralization. True, the leading Permian minerals (fluorite and barytes) are also common in the Pennines and on occasion (e.g. the fluorite cubes in geodes) of similar habit. Nevertheless, in the main the habits differ.

That is notably so with the lamellar type of crystallization, the " hopper " crystals of fluorite and the " horny " infillings of that mineral. A second view is therefore at least possible, namely that the Permian enrichments are of altogether later date than those of the Pennines and may be redistribution products of the latter either (*a*) directly, by solution of the minerals of the Pennine veins with subsequent deposition in these Permian beds, or (*b*) indirectly, by solution of the detrital barytes and fluorite according to Lewis (1923) and Versey (1925), present in the Yellow Sands. The recent formation of fluorite and blende described by Watson (1900) shows that the manner of deposition invoked for (*a*) and (*b*) is in no sense hypothetical but may be regarded as a possibility.

A third idea, put forward by Dr. Dunham to account for the small quantities of Permian ore minerals he noticed, is that they might have come from waters " poured out on the floor of the Zechstein sea by springs ; or that they might have been transported by river waters flowing from land upon which the Pennine veins outcropped ". If this means that the deposits are syngenetic the idea does not seem applicable to the minerals in these Lower Limestones, which seem rather to be deposits from veinlets.

A fourth view is that they are precipitations from descending mineralized waters of unknown origin : in view, however, of the replacement of the enclosing limestone by the invading minerals, ascending rather than descending solutions are more likely to have been operative, although this conclusion should not be stressed unduly.

Whatever their origin it seems possible that these Permian minerals may have been deposited more or less contemporaneously with those in the local Coal Measures. This view seems to gain some support from the occurrence in the Whin Houses bore of galena and sphalerite in the Coal Measures [1] as well as in the overlying Permian. This is equivalent to an acceptance of the first view put forward, despite the difference in habit of the fluorite in the Permian and Pennine limestones if, as is claimed by some authors, the minerals in the Coal Measures are due to the Pennine mineralization.

As yet, perhaps, it would be unwise to dogmatize ; one must wait for fuller and better evidence. The correct choice between the various possibilities seems of cardinal importance to the determination of the age of the Pennine mineralization.

I would like to add that I am greatly indebted to Dr. Phemister for his co-operation during the course of this investigation : in addition I owe my sincere thanks to Dr. J. A. Smythe, King's College, Newcastle-upon-Tyne, for his unfailing kindness in carrying out innumerable chemical tests.

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[1] Dr. Phemister confirmed the presence of galena and sphalerite in specimens from the Coal Measures of the Whin Houses bore ; in addition he noted irregular grains of chalcopyrite sporadically scattered on a surface on which well cleaved sphalerite crystals occur fairly abundantly.

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The Association of *Naiadites* and *Carbonicola* in a part of the Central Coalfield of Scotland

By Rhona M. MacLennan, Carnegie Research Student in Geology, University of Glasgow

THE material to be described was collected in the Shotts-Newhouse area (Sheet 31) of the Central Coalfield from the mussel bands above the Shotts Gas and presumed Lower Drumgray Coals. These horizons are within the Ovalis Zone (Weir and Leitch, 1936, pp. 704, 707). Fossils from above the presumed Lower Drumgray Coal were collected from the waste tip of South Langridge Colliery ; material from the Shotts Gas was obtained from the tips at Fortissat, Hassockrigg, and Hirstrigg collieries.

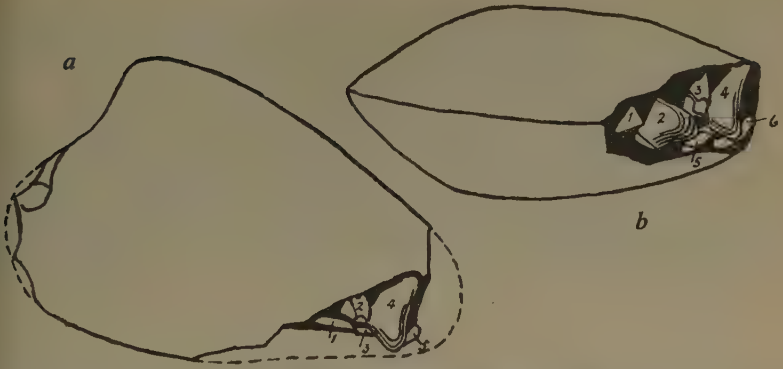
The fauna of the supposed Lower Drumgray mussel band comprises Carbonicolas varying from *C. polmontensis* (Brown) to *C. rhindi* (Brown), young forms of *Anthraconauta* aff. *minima* (s.l.) and *Spirorbis* sp. In the Shotts Gas mussel band the lamellibranchs are much more abundant. One specimen of *C.* cf. *subconstricta* (J. Sow.) has been found, the other Carbonicolas vary from *C. cristagalli* Wright to *C. rhomboidalis* Hind. *Naiadites* is also very common, belonging to the group of *N. flexuosa* Dix and Trueman, while in an ironstone layer there are numerous young forms of *Naiadites* sp. and *Anthraconauta* aff. *minima*.

Above the presumed Lower Drumgray coal, shells occur sporadically as poorly preserved solid casts in a buff-coloured mudstone. *Carbonicola* is the usual form, but an occasional *Anthraconauta* is found. *Spirorbis* is abundant, and unlike the mussels, the calcareous material of its tube is preserved. The mudstone, which is cemented by iron carbonate, is practically free from carbonaceous matter, the only vegetable remains being fragments of *Cordaites*.

The Shotts Gas mussel band is one of the better known *Carbonicola* horizons in the Central Coalfield and is fairly persistent. The fossils are usually in solid form and well preserved. The shell structure has been destroyed during replacement by iron carbonate, and a layer of siderite of varying thickness separates the inner and outer layers of shell. Occasionally the shells are found in the presumed position of life, resting on the ventral margin, but normally they lie along the bedding plane ; the umbones are often eroded. The mussel band is a tough black shale with a seam of concretionary ironstone.

During the collection of this material a number of solid specimens of *Carbonicola* were broken ; in many of these were found small *Naiadites* or less frequently specimens of *Anthraconauta*. A few of the *Carbonicolas* are gaping slightly, but the majority have the valves tightly closed. The occurrence of *Naiadites* within the closed valves of *Carbonicola* raises problems concerning the mode of life of *Naiadites*.

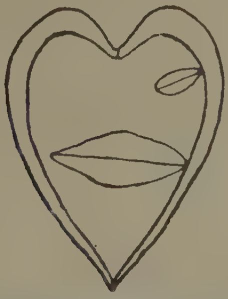
It is suggested that the frequent occurrence of *Naiadites* within the *Carbonicolas* at these horizons in the localities mentioned can only be explained on the assumption that *Naiadites* actually lived within the shell of *Carbonicola* after the death of the latter animal. It is scarcely possible that the small shells were introduced into the shell accidentally



TEXT-FIG. 1.—Specimen of *Carbonicola* from Shotts Gas mussel band, Fortissat Colliery, broken at posterior end showing within the valves a number of young *Naiadites*. (*a*) Left valve; (*b*) view along ventral margin showing that the valves are tightly closed. (Hunterian Museum No. S8020.) Slightly reduced.

after death, for it is notable that in no instance have small *Carbonicolas* been found in a like situation. Clearly, however, the *Naiadites* must have entered the Carbonicola shell when the death of the organism had permitted the partial opening of the valves by the ligament. Such a partly opened shell would probably form a sheltered habitat for the spat of *Naiadites* which became attached to the inside of the *Carbonicola* shell by a byssus and were able to feed along the opened margin of the valves. Shells of the modern *Unio* and *Anodonta* lying on the floor of modern pools similarly form havens for small aquatic organisms.

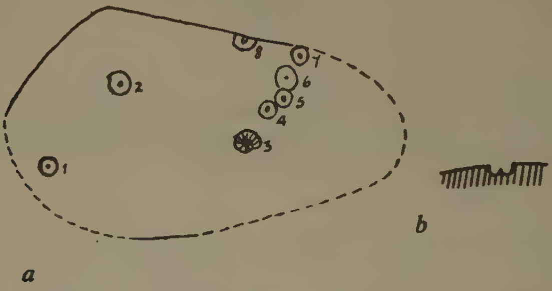
One difficulty is to explain the subsequent closing of the valves. It is suggested that this may have resulted from loss of elasticity in the ligament



TEXT-FIG. 2.—Diagrammatic section through a Carbonicola shell from Shotts Gas mussel band, Fortissat Colliery, to show two specimens of *Naiadites* in situ with their anterior ends touching the inner surface of the enclosing shell. Drawn from specimen in Hunterian Museum, No. S8021.

(a feature not uncommonly shown in modern marine shells on the shore at low tide) or simply by weight of overlying sediments. The close fit of the valves, however, and the absence of distortion indicate that in either case the " gape " of the shell could not have been very wide.

The most striking example of this association of *Naiadites* with *Carbonicola* (illustrated in Text-fig. 1) is broken at the posterior end where eight *Naiadites* can be seen ; others were observed in the middle of the shell when breakages were being repaired. The largest *Naiadites* completely visible (No. 4 in Text-fig. 1) is 13 mm. long ; a larger one is partially exposed, but the majority are between 6–8 mm. Most of these are orientated with the ventral margin towards the ventral margin of the enclosing *Carbonicola*. No. 4 in Text-fig. 1 and the two specimens illustrated diagrammatically in Text-fig. 2 lie with their anterior ends abutting on the *Carbonicola* shell. The distribution and attitude of the specimens of *Naiadites* and of *Anthraconauta* within the enclosing shell were apparently at random, for they have been found at both anterior and posterior ends, and under the umbones or towards the ventral margin.



TEXT-FIG. 3.—(*a*) Cast of *Carbonicola* sp. from supposed Lower Drumgray mussel band, South Langridge Colliery, illustrating the irregular placing of *Spirorbis* moulds on the surface of the cast. The calcareous tube of No. 3 is present in its mould. (Hunterian Museum, No. S8022.) Slightly reduced.

(*b*) Diagrammatic section across surface of cast passing through a *Spirorbis* mould.

In length the *Naiadites* vary from about 6 mm. to 25 mm., the latter measurement being the average length of the adult *Naiadites* of the Shotts Gas mussel band.

Naiadites, like its modern analogue *Dreissensia*, is believed to have lived attached by a byssus to plants, or other objects, and Wheelton Hind has figured (1893, p. 540) a fragment of wood surrounded by shells referred to *Naiadites*. He considered these specimens to be in situ While in many cases *Naiadites* probably did attach itself to vegetation, its association with *Carbonicola* at this horizon makes it clear that *Naiadites* used other convenient surfaces. The inside of a *Carbonicola* not only afforded a suitable surface for attachment but provided a shelter into which the *Naiadites* could be retracted.

In the Shotts Gas material there is only one definite occurrence of *Anthraconauta* in a *Carbonicola*, but in the Lower Drumgray all the small shells thus enclosed are apparently *A*. aff. *minima* (s.l.). A number of the casts in this latter horizon have moulds left by *Spirorbis* (Text-fig. 3). It is obvious that the specimens of *Spirorbis* were attached to the inside of the *Carbonicola*, and not to the outside of the shell as in cases recently described by Professor Trueman (1942, p. 313). In this connection it is noteworthy that these Spirorbids are distributed irregularly over the surface of the casts. In some cases the calcareous tube of *Spirorbis* is itself preserved, showing the smooth surface by which it was cemented to the inside of the *Carbonicola* shell. The fact that these Spirorbids were undoubtedly attached to the inside of the shells makes it clear that for a considerable period, probably at least six months, the dead *Carbonicola* shell was lying with valves partly opened on the floor of the " lagoon ", and that it was subsequently closed : this affords important confirmation of the views concerning the occurrence of *Naiadites* discussed above.

Within most of the *Carbonicola* shells several generations of *Naiadites* are represented. While the rate of growth of *Naiadites* is unknown, it is unlikely that the largest specimens seen were less than two years old. During this time the *Carbonicola* shell must have lain with its ventral margin above mud level and must presumably have been comparatively free of mud on the inside. This would indicate, especially in the case of the Shotts Gas mussel band, which contains a high percentage of carbonaceous matter from vegetable decay, that the rate of accumulation of mud was extremely slow, and may indeed have ceased temporarily, especially during the formation of the ironstone.

ACKNOWLEDGMENTS

In conclusion the writer would like to express her indebtedness to Professor Trueman for his aid and valuable suggestions at all times. Thanks are also due to the Council of the Edinburgh Geological Society for a grant from the Clough Memorial Fund towards expenses incurred during field work ; and to Dr. M. Macgregor and Mr. W. Manson, of H.M. Geological Survey in Scotland for information given.

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Hypostomes of Some Girvan Trilobites and their Relationship to the Cephala

By James L. Begg

(PLATE II)

I. Introduction

THE Palaeozoic rocks of the Girvan district have long been known for their rich faunal content, which has been studied by many palaeontologists. Trilobites are so abundant that they have been dealt with in a special monograph by Reed (1903–6). Since the publication of the monograph, however, continued collecting has made possible the description of further species and the amplification of many of the original descriptions; much of this has been accomplished by the publication of three supplements to Reed's monograph. The present paper is devoted to a consideration of the hypostomes of some Girvan trilobites. Professor A. E. Trueman has taken a keen interest in its preparation, and I desire to thank him for his very valuable assistance in correcting and improving the text; I must acknowledge again my indebtedness to Dr. F. R. C. Reed for the loan of literature.

II. Re-descriptions of Certain Hypostoma

Hypostoma from the Girvan District have been either described or figured in *Dionide*, *Lichas*, *Proetus*, *Isotelus*, *Bronteopsis*, *Stygina*, *Calymene*, *Phacops*, *Cheirurus*, *Encrinurus*. Continued collecting in Girvan localities has furnished other examples in the genera *Lichas*, *Proetus*, *Stygina*, *Encrinurus*, and *Calymene*. Hypostoma of these have been found in their natural position in relationship to the cephala and call for an emended or amplified description.

LICHADIDAE Corda

Lichas (*Hemiarges*) *maccullochi* Reed. (Pl. II, fig. 6)

Hypostome No. BG 5404. The following description is based upon a hypostome *in situ* underlying the cephalon, all of which has been removed save the lateral lobes on the left side of the glabella. The outline is subquadrate to circular, with well-rounded angles; it is wider than long, the greater width being at the posterior. The anterior margin is gently convex, the posterior one slightly concave. An elevated ridge, triangular in section, corresponding to an external groove on the ventral surface, separates the central area from the broad, flattened, lateral, and posterior borders. At either end it curves forward and outward, coming into contact at an acute angle with two similar but shorter ridges which likewise curve forward and outward, dying out towards the lateral margins. The central area is depressed corresponding to the convexity of the ventral surface. This specimen shows feeble ornamentation, but in other examples BG 3305, 3307, 3219, 7561 it is well shown. The central area appears, from the pits on this side, to be coarsely punctate on the external surface; the broad flattened borders bear terraced lines parallel to the margin thus indicating the extent of the area occupied by the hypostomal doublure. The most interesting feature of this hypostome is a transverse groove, semicircular in section, just within the anterior margin; it is sub-parallel to the margin, being less arched and thus leaving a narrow crescentic area between the groove and the anterior margin. Into this groove a raised band or girder on the ventral side of the cephalon is seen to dovetail, and it is evident that these two together functioned in the articulation of the hypostome. This hypostome is comparatively large, occupying a space greater than one-half of the total area of the cephalon. Its posterior end reaches as far backward as the nuchal furrow.

Dimensions.—Length, 6·5 mm.; posterior width, 8 mm.; anterior width somewhat less.

Horizon.—Ashgillian, zone of *Dicellograptus anceps.*

Locality.—Upper Starfish Bed, Lady Burn, Girvan.

Lichas (*Euarges*) *geikiei* Nicholson and Etheridge

No. BG 3109. In the Upper Starfish Bed in association with the former species *L. maccullochi* quite a number of specimens of *Lichas geikiei* were obtained. In many of these the hypostome was partially or entirely exposed, but in no instance was it found so well preserved as in the larger species *L. maccullochi*, the anterior portion usually being defective. The hypostome of this species closely resembles that of *L. maccullochi.* The anterior groove described in *L. maccullochi* is present and well seen in a number of individuals. The posterior border of this species, however, presents a peculiar feature. The lines are no longer parallel with the posterior margin but continue in the same direction as the lines on the lateral borders and are sub-parallel to the median line of the animal. These terraced lines are narrow, elongate, spindle-shaped, and separated from one another by deeply impressed, narrow channels.

Dimensions.—Approximate length, 4 mm.; approximate width, 5 mm. Same horizon and locality.

PROETIDAE Corda

Proetus girvanensis Nicholson and Etheridge. (Pl. II, figs. 7, 7*a*)

Proetus procerus Nicholson and Etheridge 1879 was redescribed and igured by Reed (1904, p. 77, pl. xi, figs. 5, 6, 6*a*). The present writer (1939, p. 372) is of opinion that this form is cospecific with *P. girvanensis* Nicholson and Etheridge. The hypostome which was described and figured (Reed, 1904, p. 78, pl. xi, figs. 6, 6*a*) was stated to be in a poor state of preservation, occupying a normal position and about two-thirds he length of the glabella. It was further stated that " its rounded extremity as a flattened band pressed against it ". The hypostome of a specimen ecently collected is rather rugged, being preserved in a coarse matrix. Nevertheless, it is evident that a flat band surrounded the whole hypostome; aterally and posteriorly the band is narrow, round the almost semi-ircular anterior border it is somewhat broader. For a short distance rom the acute antero-lateral angles the lateral borders are directed orizontally inward, then taper gently backward for two-thirds of the length of the hypostome (which is here constricted), their course is then backward and slightly outward to the postero-lateral angles ; the posterior extremity is rather bluntly pointed. The body of the hypostome is convex transversely, less so longitudinally. The posterior end of the central mass is rounded. With the exception of the well-rounded anterior, the outline of our example is angular and characteristic of the generic type of *Proetus* hypostome. It reaches as far posteriorly as the nuchal furrow of the glabella.

Material.—One example only, BG 8341, which was obtained by splitting.

Dimensions.—Length, 3 mm. ; anterior width, 2·75 mm.

Same horizon and locality.

STYGINIDAE Raymond

Stygina latifrons (Portlock). (Pl. II, fig. 5)

Reed (1914, p. 18) in his description of the hypostome of this species states that " a pair of large upturned alae, not marked off by any furrow from the body, lie at the anterior lateral angles of the hypostome ". In an impression taken from an external mould we find that a pair of broad, shallow, but defined furrows do exist separating the alae from the central area of the hypostome. This impression shows that a border with a narrow rim surrounds the lower portion of the hypostome, but is delimited in its anterior course where it dies out against the alae ; a pair of small tubercles, within the outer rim, are situated towards the posterior.

Material.—One example, No. BG 3308, which, with the glabella removed, exhibits the external mould of the hypostome.

Dimensions.—Length, 6 mm. ; width at anterior, 9·5 mm.

Same horizon and locality.

ENCRINURIDAE Angelin

Encrinurus multisegmentatus (Portlock) var. *girvanensis* Reed. (Pl. II, fig. 4)

BG 7573. A poorly preserved hypostome of this trilobite has been figured by Reed (1906, pl. xvi, figs. 11, 11*a*) and another described by him (1935, p. 50). A further specimen recently collected differs somewhat from the latter in having its arched anterior end bluntly rounded and not " acutely pointed in front ". Further, in our example at its greatest width, a solid, round process projects outwards at right angles to the longer axis of the hypostome and appears to curve slightly upward. This process is a continuation of the hypostome and evidently functioned in its articulation. It has no connection with the finger-like process described by Whittard (1938, p. 120, pl. iv, fig. 7) in *E. onniensis*, which was an extension from the dorsal surface and articulated with a socket on the anterior wing of the hypostome ; in *E. multisegmentatus* the process is developed from the wing itself.

Material.—One example preserved in the coarse matrix of the Starfish Bed.

Dimensions.—Length, 5 mm. ; width, 4 mm.

Horizon and Locality.—Ashgillian, Drummuck Group, Lower Starfish Bed, Lady Burn, Girvan.

Remarks.—Hypostoma are often found with this process either lacking or remaining unexposed. In the present instance it is only preserved on one side. It should be pointed out that Whittard (*ibid.*, p. 119) is of opinion that in *Encrinurus* there is a very considerable variation in the rostal plate, that the methods of the articulation of the hypostome vary, and he considers that these features should play an important part in the determination of species of the genus.

III. New Hypostoma

Hypostoma of the following species have been obtained by recent collecting and are recorded here for the first time. *Illaenus longicapitatus* Reed, *Phillipsinella parabola* Barrande, *Phacops retardatus* Reed, *P. elliptifrons* Sars & Boeck, *Cybele* (*Cybeloides*) *lovéni* Linnarsson var. *girvanensis* Reed, and *Sphaerocoryphe thomsoni* Reed.

Descriptions

ILLAENIDAE Dalman

Illaenus longicapitatus Reed. (Pl. II, figs. 1, 1*a*)

Hypostome No. BG 7669, 7669*a*. A cephalon, an epistome, and hypostome of this species are almost perfectly preserved. The epistome is attached in place and the hypostome is practically *in situ*. The epistome has a close resemblance to that of the Silurian species *I. thomsoni*, figured by Reed (1904, pl. x, fig. 2). It is similar in outline and bears the same broad terraced lines, which number 10 in each instance. Anteriorly the hypostome is in close proximity to the epistome, but is bent upward making an angle of over 90 degrees with the plane of the epistome and is approximately parallel to the steep, downward-curving, anterior portion of the cephalon. The hypostome is subquadrate in outline with well-rounded angles ; the sides taper to the obtuse postero-lateral angles. The central mass is convex, and the greatest height is at the anterior, from which it slopes down to the lateral and posterior borders. Short, narrow, slightly upturned alae are present at the antero-lateral angles, in form resembling the upper half of a crescent. The anterior margin is straight for the greater part of its length, curving round suddenly at the angles. A narrow rounded rim is present on the lower two-thirds of the hypostome, being delimited at the base of the alae. This marginal rim is separated from the central mass by a somewhat uneven and slightly undulating band, which is narrow at its origin at the alae, increasing gradually in width towards the posterior end where it is broadest. If the specimen is held in a horizontal position and viewed from the posterior (fig. 1*a*), that end appears as a low arch upon which, medially and close to the margin, there is an increased convexity or low flat dome ; further inward towards the postero-lateral angles a pair of small round tubercles are present.

If still held in this position an interesting feature is seen ; the lateral and posterior rims unite to form a process which is directed downwards at a high angle to the plane of the hypostome, from the postero-lateral angles it curves, first outward, then inward, in such a manner that it becomes confluent with the arched posterior margin of the hypostome.

Material.—One example obtained by splitting. Specimens being abundant, a cephalon which had the epistome exposed on the under side was selected and split. The fracture had its course across the plane on which the hypostome had been entombed.

Dimensions.—Length, 8 mm.; anterior width, 11·25 mm.; length of process, 2·25 mm.

Horizon.—Ashgillian, zone of *Dicellograptus anceps.*

Locality.—Lower Starfish Bed, Lady Burn, Girvan.

Family ? STYGINIDAE Raymond

Phillipsinella parabola Barrande. (Pl. II, fig. 8)

Hypostome No. BG 8211, 8211*a*. The hypostome of this species has a very simple form. It occupies a position immediately behind the large swollen anterior lobe of the glabella and reaches as far back as the extreme end of the cephalon. The anterior border is too poorly preserved to be clearly defined, but it appears to have been nearly straight. The body is convex transversely, nearly parallel-sided, with a slight swelling at mid-distance which gives it a rather ovoid appearance. The posterior end is well-rounded. Laterally and posteriorly there is present a high rim which is separated from the central area by a deep channel.

Dimensions.—Length, 5 mm.; greatest width, 2·75 mm.

Horizon.—Ashgillian, zone of *Dicellograptus anceps.*

Locality.—Upper Starfish Bed, Lady Burn, Girvan.

Remarks.—Reference of this genus to the Styginidae of Raymond (1920, p. 283) is queried above because although it is a much more appropriate family than the Proetidae in which the genus was formerly placed, the characters of the cephalon in *Phillipsinella* are very distinct from those of *Stygina*, *Bronteopsis*, and *Holometopus*. Novák (1885, figs. 2–3) has wrongly interpreted the impression of a broken-off part of the anterior glabellar lobe of this species as a hypostome; it is clear from the specimen illustrated (pl. ii, fig. 8) that in this species as in *Sphaerocoryphe thomsoni* (Begg, 1940, pl. iv, figs. 4, 6), the hypostome is posterior to the anterior lobe.

PHACOPIDAE Corda

Phacops (*Pterygometopus*) *retardatus* Reed. (Pl. II, fig. 10)

Hypostome No. 8208*a*. The hypostome of this species has the subtriangular outline characteristic of the genus. It is broadest at its anterior: from the antero-lateral angles the sides taper rapidly backward for about one-third the length, then less so, in a slightly curving line to the posterior end which is not well preserved. The anterior margin is probably slightly arched, judging from the portion not obscured by matrix, which is about one-half of its course. Moderately large alae are present; they are triangular in form and their lateral extension is equal to about one-half the width of the anterior portion of the body. A narrow lateral border runs from the alae on either side to the posterior end where it becomes broader. Towards the posterior end a transverse furrow delimits the body and marks off a short, crescentic, posterior area. The posterior end of the hypostome lies beneath the nuchal area of the cephalon, which is also the case in other species of *Pterygometopus*.

Material.—One specimen No. BG 8208*a*. The description is taken from a wax impression of an external mould.

Dimensions.—Length, 9·5 mm.; width (greatest anterior), 12 mm. Same horizon and locality.

Phacops elliptifrons Sars and Boeck. (Pl. II, fig. 9)

Hypostome No. BG 8715. The anterior border is arched in its middle course, otherwise the hypostome would possess an almost triangular outline. Round the arched central portion of the anterior there is a flat, upturned band which, if ever present in the outer, more horizontal portions, does not appear to have been preserved there. Only one of the alae at the antero-lateral corners has been preserved; this is triangular in form and its extent, in relation to the length of the hypostome, cannot be estimated as the posterior portion of the hypostome is missing. The sides taper backward rapidly for the anterior part of their course, then less so. The central mass is convex transversely, particularly anteriorly.

Material.—One example, incomplete on one side and posteriorly.

Dimensions.—Length, ?; anterior width, 7 mm.

Locality.—A ditch in a moor north of Mulloch Hill, where the species, as at Newlands, is found in abundance.

Remarks.—I think that there can be little doubt that this hypostome is referrable to *P. elliptifrons*. Not only was it found in association with that species, but *P. elliptifrons* is the only *Phacops* of Valentian age known to me in the Craighead Inlier.

ENCRINURIDAE Angelin

Cybele (*Cybeloides*) *lovéni* Linnarsson, var. *girvanensis* Reed.

(Pl. II, figs. 2, 2*a*)

Hypostome No. BG 8217. In outline the hypostome of this *Cybele* is subtriangular and elongate. The greatest width is anterior; it tapers from the antero-lateral angles to a well-rounded posterior end. The anterior border is flatly arched, with a narrow rim separated from the body by a broad, shallow furrow; a narrow border, beginning at about one-third the distance from the anterior end, gradually increases in width in its course to the posterior end, where it appears as a small crescentic area behind the body of the hypostome. The body is strongly convex transversely and from anterior to posterior; its greatest elevation is near the middle from which it slopes down steeply to the lateral and posterior borders; less so to the anterior one. The anterior border extends beyond the lateral borders and in the angle so formed there appears to be the broken-off base of an articulating process. The position of this is about one-fourth the distance from the anterior. The posterior end of the hypostome lies beneath the nuchal furrow on the dorsal surface. The genus *Cybele* is allied to that of *Encrinurus* so that a process of this nature might be expected.

Material.—One example No. BG 8217. A specimen was split in an endeavour to find the hypostome. As the result of two fractures a small median part was obtained with the glabella on one side and the hypostome attached beneath.

Dimensions.—Length, 5·50 mm. ; anterior width (estimated), 3·50 mm.

Horizon.—Ashgillian, zone of *Dicellograptus anceps*.

Locality.—Upper Starfish Bed, Lady Burn, Girvan.

CHEIRURIDAE Salter

Sphaerocoryphe thomsoni Reed

A hypostome of this species has already been described and figured (Begg, 1940, p. 300, pl. iv, fig. 4), and it is only necessary here to refer to the position which it occupies. Its anterior border is in juxtaposition with the posterior end of the swollen, anterior lobe of the glabella, and it reaches as far back as the posterior end of the headshield.

Cheirurus elongatus Reed

This new species was described and figured by Reed (1931, p. 105, pl. iv, figs, 5, 7, pl. v, fig. 4). The hypostome which is referred to this species was not found in contact. It is elongate in form. Measurements were made of normal, mature cephala of the species and the hypostome, and from the comparison there can be little doubt that the hypostome is properly referred to this species, and that it extended to the posterior of the headshield.

Horizon and Locality.—Mid. Valentian, Saughhill Group. Newlands, near Girvan.

CALYMENIDAE Milne Edwards

Calymene drummuckensis (Reed). (Pl. II, fig. 3)

Isolated hypostoma of this species have already been recorded from the Drummuck Group and figured. The present example, although both incomplete and imperfect, is seen in its natural position with the posterior extremity reaching the base of the headshield.

Material.—No. BG 9795, one specimen obtained by splitting a headshield of the species.

Dimensions.—Length, 3·50 mm.

Horizon and Locality.—Ashgillian, zone of *Dicellograptus anceps*, Upper Starfish Bed, Drummuck Group, Lady Burn, Girvan.

IV. CONCLUSIONS

The writer has been able to determine the relationship of the hypostom to the cephalon in eleven species of Ashgillian age from the Girva district. It has been found that in examples of eight of these eleve species the hypostome has been preserved in the position which i occupied in life : in these the hypostome extended backwards on th ventral surface to a position corresponding to the nuchal furrow on th dorsal surface. These eight species are :—

Proetus girvanensis Nicholson & Etheridge
Lichas geikiei Nicholson & Etheridge
Lichas maccullochi Reed
Phillipsinella parabola Barrande
Calymeme drummuckensis (Reed)

Phacops retardatus Reed
Cybeloides lovéni (Linnarsson) var. *girvanensis* Reed
Sphaerocoryphe thomsoni Reed

With regard to the remaining three species from the Ashgillian rocks it is probable that in *Encrinurus multisegmentatus* the hypostome had a similar extent, though it has not been satisfactorily demonstrated. In *Stygina latifrons* the hypostome does not appear to extend so far as the posterior extremity of the cephalon, while in *Illaenus longicapitatus* the epistome and hypostome do not extend backwards for more than half the length of the cephalon. A similar relation is found in the only common Asaphid represented in the Girvan district, *Isotelus instabilis* from Dow Hill, in which the hypostome extends posteriorly for about two-thirds of the length of the cephalon. It may be significant that in each of the three last-mentioned genera glabellar furrows are absent.

A hypostome of *Phacops* (*Chasmops*) *bisseti* figured by Reed (1914, pl. viii, fig. 4) appears to reach the posterior end of the head-shield, which is indicated in the drawing.

Hypostomes of three mid-Valentian species, *Calymene* cf. *blumenbachi* (from the Saughhill Group), *Cheirurus elongatus* Reed and *Phacops elliptifrons* Sars and Boeck have been found at Girvan. They are isolated from the head-shields, but on making comparisons with the size of head-shields of those species normally found it appears highly probable that in those also the hypostome reached the posterior part of the cephalon.

It may also be recorded that in an example of an American species (*Calymene platys* Green) in the writer's collection, the rostal plate is completely preserved. Although the hypostome is lacking it is clear from the position it occupied that it reached the posterior region of the head-shield.

It may thus be concluded that there appears to be good evidence for the view that in many late Ordovician and Silurian species, where the relative size of the hypostome has been determined, it extends back to a position as far as the nuchal furrow on the dorsal surface.

In many earlier trilobites the hypostome appears to have been of relatively smaller size. Thus Stubblefield has noted that it " is attached to the doublure so as to lie beneath the front part of the glabella " (1936, p. 407) : the illustrations of the ventral side of trilobite cephala given by Stubblefield (partly after Richter, 1932) clearly show the relatively short hypostomes in a number of genera (1936, fig. 2), though considerable variation in proportion is shown by those figured.

So far as can be ascertained, the hypostome occupied an anterior position in many Cambrian trilobites, and it is suggested that a greater extension was a character of some later forms.

If we accept the widely-adopted view that the glabellar furrows were concerned with the attachment of muscles which functioned in the articulation of the hypostome, it may be suggested that its greater length may have been connected with the backward extension of the glabellar furrows in some forms.

It is well known that in many Cambrian genera the glabellar furrows show a primitive pattern, running transversely to the axis of the glabella.

In later trilobites the furrows have undergone considerable modification, being directed inward and forward or inward and backward : the latter tendency has in some instances led to the formation of a detached or a discrete lobe. These changes in the glabellar furrows of the Calymenidae have been traced by Elles (1923, pp. 83–107). The more complex pattern of later forms may be related to muscle attachments in trilobites in which the size and articulation of the hypostome were perhaps being modified.

Consideration of the above observations on hypostomes suggests interesting speculations regarding the appendages of the cephalon. The extension of the hypostome in these later genera may have led to modifications in the appendages. The four pairs of biramous appendages which Raymond (1913, p. 702) considered to occur posterior to the hypostome in some types must, if they persisted, have been greatly changed when so little room remained for their attachment. It is to be hoped that trilobites sufficiently well-preserved to show the appendages of this region and with relatively large hypostomes may be found in the future.

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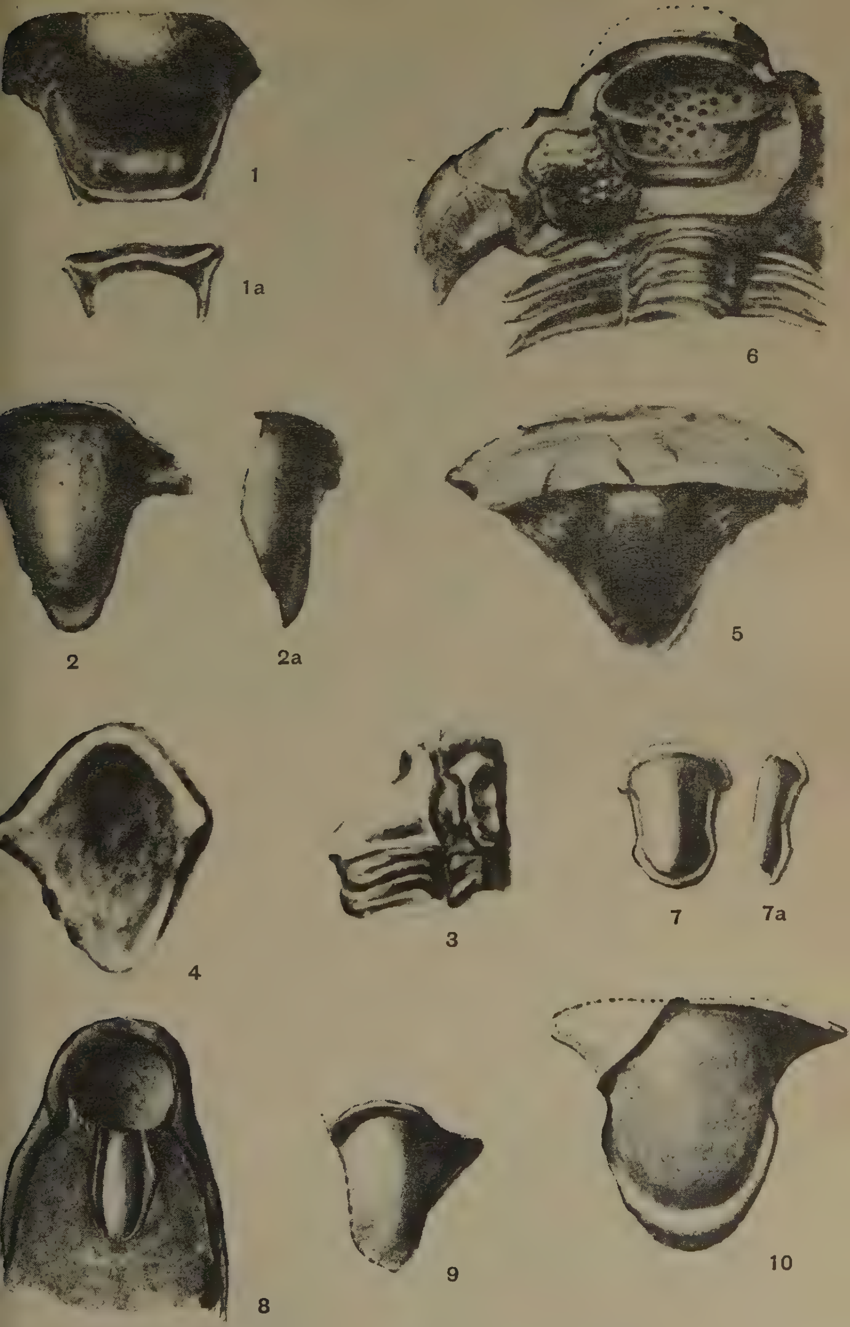
EXPLANATION OF PLATE

All specimens are in the J. L. Begg Collection

Fig. 1, 1*a*.—*Illaenus longicapitatus* Reed. No. BG. 7669*a*. Fig. 1, ventral aspect of hypostome ; fig. 1*a*, view of posterior extremity when specimen is held horizontally. Horizon and locality, Ashgillian, zone of *Dicellograptus anceps*, Upper Starfish Bed, Lady Burn, Girvan. × 3.

Fig. 2, 2*a*.—*Cybele* (*Cybeloides*) *lovéni* Linnarsson, var. *girvanensis* Reed No. BG. 8217. Fig. 2, ventral aspect of hypostome imperfect on one side ; fig. 2*a*, side view of the same specimen. Same horizon and locality. × 5.



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Hypostoma of Girvan Trilobites

FIG. 3.—*Calymene drummuckensis* Reed. No. BG. 9795. An imperfect hypostome in its natural position ; the posterior extremity reaches the base of the headshield. Same horizon and locality. × 3½.

FIG. 4.—*Encrinurus multisegmentatus* (Portlock) var. *girvanensis* Reed. No. BG. 7573. Dorsal view of an isolated hypostome ; the base of a broken off process is seen on one side. Same horizon ; Lower Starfish Bed, Lady Burn, Girvan. × 6.

FIG. 5.—*Stygina latifrons* (Portlock), BG. 3308. A hypostome in contact with a finely striated epistome. Same horizon, Upper Starfish Bed, Lady Burn, Girvan. × 3½.

FIG. 6.—*Lichas maccullochi* Reed. No. BG. 5404. An incomplete headshield which being partly removed exposes the greater part of the hypostome in its dorsal aspect and in its natural position. The anterior groove of the hypostome is in contact with the ventral side of the glabella, parts of which are visible at both ends of the groove. Same horizon and locality. × 3¾.

FIG. 7, 7*a*.—*Proetus girvanensis* Nich. and Ether. No. BG. 8341. Fig. 7, drawing of a hypostome which is in situ beneath the glabella ; fig. 7*a*, side view of the same specimen. Same horizon and locality. × 6.

FIG. 8.—*Phillipsinella parabola* Barrande. No. BG. 8211. A ventral aspect of the hypostome in situ, the anterior is slightly abraded. The thorax and pygidium are preserved on the other side of the specimen. Same horizon and locality. × 2½.

FIG. 9.—*Phacops elliptifrons* Sars and Boeck. No. BG. 8715. An isolated imperfect hypostome. Apart from the posterior extremity the general aspect is apparent. Horizon and locality. ? Saughhill Group ; specimen found in an exposure north of Mulloch Hill near Girvan. × 4.

FIG. 10.—*Phacops retardatus* Reed. No. BG. 8208*a*. An almost complete hypostome. Drawing made from an impression in wax taken from an external mould of a complete individual with the cephalon defective. Horizon and locality, Ashgillian, zone of *Dicellograptus anceps*. Upper Starfish Bed, Lady Burn, Girvan. × 3¼.

A Comment on a New Area of Slumped Beds in Denbighshire

By O. T. Jones

IN a recent paper on the Wenlock and Ludlow rocks of the district around Gwytherin, North-Western Denbighshire,[1] Professor Boswell deals with an area which lies to the south of the Llangerniew district that I mapped and described a few years ago.[2]

In that area he has recognized and mapped a considerable tract of slumped beds similar to those which occur on a large scale in the Llangerniew district. The section (fig. 10) implies in fact that this newly discovered outcrop is a continuation southward of the Llangerniew slumped beds repeated by shallow east-west folding.

I am gratified to find that Professor Boswell adduces some evidence that the disturbances of these beds were contemporaneous. His conversion to the view which I first put forward for that area is apparently still only partial, for he writes, " The disturbances may date from a period shortly after their deposition (that is, it is due to contemporaneous or penecontemporaneous sliding (or ' slumping '), or it may date from some later epoch when earth movements were in progress, or as I rather think, from both such periods."

This paragraph betrays some confusion between two types of structure which can be recognized in these remarkable rocks but are of different origin. It is obvious that if the disturbed beds were in existence before the post-Silurian movements they must have been affected by those movements in common with the overlying and underlying undisturbed sediments, and so far as I know this fact has never been disputed. The main structure caused thereby is a rude form of cleavage and of course, as I maintained, the rocks have been cut by a large number of faults, which slice across country without regard to the pre-existing structure of the strata. The point at issue between Professor Boswell and myself has been whether the structures which give these disturbed rocks their *distinctive* characters were due to contemporaneous sliding or slumping on the sea floor or were produced by subsequent earth movements acting on selected layers of strata leaving the interbedded strata devoid of such structures.

These distinctive structures are extreme contortion, acute folding frequently isoclinal or even recumbent, slides separating masses of one structure from those of another, " balling up " of mudstones and other structures which I have described fully and illustrated elsewhere.[3] In this latter publication I formulated a crucial test of the date of origin of the disturbed beds and I gave a long list of localities where the junction between disturbed beds and the next overlying layer of normal sediments can be examined (pp. 375, 376). In all these sections the rocks have

[1] *Proc. Liverpool Geol. Soc.*, xviii, pt. iii (1942), 86–100, with Geological sketch map (fig. 9) and section (fig. 10).

[2] *Quart. Journ. Geol. Soc.*, xciii (1937), 241–282.

[3] The Geology of the Colwyn Bay district. *Quart. Journ. Geol. Soc.*, xcv, 1940, 335–382.

nowhere been affected by subsequent movements in such a way as to produce sliding of one rock on the other at the contact. The beds now show the same mutual relations as they did when the overlying undisturbed beds were laid down on the sea floor. The disturbed beds at and below the contact contain one or more of the structures which are distinctive of them and in many cases the layers of rock participating in these structures are truncated at the top of the sheet. In the great majority of cases, if not in all, the basal layer of the overlying normal straight-bedded sediments is graded from coarse silt or sand or even pebbles at the bottom to silty mudstones above. The grading is completed within a thickness of a few inches above the contact. Moreover the structures which are distinctive of the disturbed beds immediately below the contact are all absent from the normal sediments. The conclusion to be drawn from the examination of these contacts is inescapable, and it is that the disturbed beds possessed their distinctive characters as they lay on the sea floor ready to receive the next layer of undisturbed but graded sediments. This is what I understand by the disturbances being contemporaneous. It is only if such a sharp contact does not occur and there is moreover clear evidence that the disturbed beds pass upwards conformably into a substantial thickness of undisturbed beds that the idea can be entertained that the sliding or slumping may have been delayed until at least the deposition of the overlying undisturbed sediments was completed, and may therefore be described as penecontemporaneous. I have seen no example of disturbance in Denbighshire which cannot be described as contemporaneous.

It is not without an element of humour that Professor Boswell in this paper charges me with having missed some slumped beds which are said to occur within the area of my Llangerniew map. He remarks (p. 90) that I have included in my map " one *important* area which falls within the map that accompanies this paper (fig. 9). It is the district occupied by disturbed rocks around Wern and Ty'n-y-caeau ". (The italics are mine.) I have not really included this area within my map since Wern only just falls within the band of colour edging which encloses the slumped beds on the south and defines the edge of my map. The lithographer attempted to reproduce the colour edging by a system of firm lines passing into broken lines towards the margin of the band. Wern occurs just within the broken-lined area but Ty'n-y-caeau is a mile farther south on the blank part of the sheet. West of Wern is a heavily drift-covered area under which I indicated the approximate position of the Llangerniew fault and inserted a narrow band of colour to indicate the juxtaposition of normal sediments on the east side of that fault and disturbed beds on the west. Whether the slumped beds which are mapped by Professor Boswell near Wern extend into that area no one can tell in view of the heavy drift cover and the presence of a fault ranging towards Wern from the north-east.

To the best of my recollection the ground that I mapped only extended a short distance south of the road from Llangerniew to Llansannan about one mile north of Wern.

I am unable to follow the intention in Professor Boswell's mind in a further statement (p. 90) that " streams and roadside sections up to half a mile in length within it [the area of slumped beds mentioned above] furnish excellent exposures of disturbed beds although if viewed from afar its smooth topography suggests that it is underlain by normal sediments. (Possibly that is why it was so delineated on Professor Jones's map) ". The simple answer to this question is, as I have shown above, that I did not delineate it, but the paragraph seems to convey a further suggestion that I mapped the area by viewing it " from afar ". If this is the intention I can assure Professor Boswell that I have never been guilty of such a gross departure from good mapping technique. The boundary lines and faults on my field maps were always drawn on the ground with due regard to all the evidence available and were not inserted indoors at some later time. If on further consideration some additional lines seemed to be required the ground was visited again before any such lines were inserted.

A small area near the northern margin of Professor Boswell's map is in common with my Llangerniew map and it is of interest to compare his new lines with my own and with his earlier lines for the same boundary.[1] West of the remarkable exposure in the roadside quarry near Ty'nyffordd Professor Boswell's new boundary line is shown as thrown up by small faults in ascending the scarp to the west and the line is almost identical with my own. Farther west there are minor differences, such as may well occur in that poorly exposed ground.

It is highly probable that the slumped beds mapped by Professor Boswell south of Pandy Tudyn are, as he suggests (fig. 10), a southward extension of the Llangerniew series repeated across a low anticline. The exposed thickness is apparently some 200 feet and must presumably be compared with the lower part of the main series which is exposed north of Ty'nyffordd. The section along the Afon Derfyn valley is said to exhibit several sheets of disturbed beds with interbedded normal sediments. It would be of interest to have had a further description of these relationships and of the contacts between normal and disturbed sediments if any such are exposed. These intercalations of undisturbed mudstones indicate in all probability that the continuous mass of slumped beds north of Ty'nyffordd in which such intercalations are wanting tends to break up within a short distance to the south into alternate bands of disturbed and normal sediments in the same manner as does the Llangerniew series when traced eastward towards Tryfan, Moel Prion, and Gyffylliog.

After such a promising start it is disappointing to find that Professor Boswell has recorded the beautiful series of slumped beds exposed on Moel Pentre Wern as if they were normal sediments of Upper Nilsson age. They cannot be distinguished in any essential particular from those on the west side of the valley near Llangerniew, of which they are in fact the direct structural continuation.

Another small area near Rhwngyddwyffordd on the western margin of the area is also shown apparently as normal sediments although there are fine exposures of typical slumped beds to the south of that place on the old road to Nebo.

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[1] *Proc. Liverpool Geol. Soc.*, xvi, 1931–2, 18–32.

Notes on Certain Upper Devonian Brachiopods figured by Whidborne

By F. R. C. Reed

Part I

The Whidborne Collection of Devonian fossils from Devon and Cornwall now in the Sedgwick Museum, Cambridge, contains the majority of the specimens and nearly all the types described and figured by him in his memoir published by the Palaeontographical Society, vols. xlii–lii, between the years 1889–1898. The following notes have been made on a re-examination of certain of his Upper Devonian specimens in the light of more recent work and other material, though unfortunately many of the fossils are too imperfectly preserved for a satisfactory determination. A comparison of several of the species with those of Sowerby's types described and figured in 1840[1] has been of much value. Those specimens in the Whidborne collection which require no further remarks or are so poor that a correct identification is deemed at present impossible are omitted.

The question of the reference of the Pilton beds to the Lower Carboniferous rather than to the Upper Devonian is unsettled, but if we agree to their equivalence to the Etroeungt beds of the Continent it seems that we must regard them in the present state of our knowledge either as passage beds or as marking the lowest horizon of the Carboniferous. The intermixture of the faunas (if it actually occurs), and so far as the stratigraphy of the Pilton beds has been revised, inclines the present author to prefer to regard them as passage beds. The most recent discussion of their age and position is that by Paul in 1937 who brings forward strong reasons for putting them in the Lower Carboniferous. But it has been suggested that two different stratigraphical horizons have been included under the term " Pilton beds ", and that only the part containing members of the trilobite genus *Phacops* are of Upper Devonian age. Further detailed mapping and collecting from the type localities are required before the question can be settled. The problem of a satisfactory line of division between the Devonian and Carboniferous also exists in America, and has been discussed by Chadwick (1935).

BRACHIOPODA

Genus : Productella Hall

The genus *Productella* was founded by Hall in 1867 on specimens from the Hamilton formation of Kentucky which he referred to the European species *Productus subaculeatus* Murchison 1840, and therefore this species has been always taken as the genotype. But Schuchert (1897, p. 318) has stated that all the American shells assigned to this species belong to *Productella spinulicosta* Hall (1867, p. 160, pl. xxiii, figs. 25–34), and Dunbar and Condra (1932, p. 192) have expressed the opinion that the genus *Productella* is composite and includes the ancestral radicles of several later genera. Such had been previously suspected by the author in the case of British Devonian shells, and Sutton (1938, p. 550) says that "careful examination of the Mississippian forms referred to that genus indicates that most of them should probably be assigned elsewhere". Indeed he considers that *P. pyxidata* (Hall) (Sutton, 1938, p. 551, pl. 62, figs. 3, 4) is the only Mississippian species [1] which possesses the diagnostic characters of the genus, but he does not deal with Devonian species. Caster (1939, p. 120) questions whether Murchison's species can stand as the genotype. We can, however, recognize that more than one genus or at any rate subgenus can be distinguished amongst the British forms from the Pilton beds, and that in spite of their generally unsatisfactory state of preservation and imperfect condition most, if not all, cannot be associated with the typical *P. subaculeata*. One of these is *Leptaena caperata* Sowerby, which as demonstrated below, should be separated from *Strophalosia productoides* (Murchison) to which it has been usually referred, and also from typical members of *Productella* sens. str. (as re-defined by Sutton) in which genus also it has frequently been placed. For Sutton's definition of *Productella* is as follows : "Shell below medium size, deeply concavo-convex, with the curvature of the brachial valve following closely that of the pedicle-valve, forming a thin visceral cavity. Hinge-line straight, equal to or a little shorter than the greatest width. Narrow cardinal area on both valves, generally somewhat wider on the pedicle-valve in Mississippian species. Delthyrium closed by deltidium. Cardinal teeth in pedicle-valve, dental sockets, and socket plates in the brachial. Surface of valve sparingly spinose, with the spines more or less irregularly arranged. Radiating markings more or less discontinuous, often elongate node-like elevations rather than continuous costae. Concentric markings also rather indistinct. The indefiniteness of both radial and concentric markings is in contrast to most members of the Productidae. Internal features quite similar to those of other productids. The cardinal process is bilobed, with each of the two lobes appearing bilobed because of a small incision in the distal portion." Paeckelmann's (1931) interpretation of this genus does not agree, but he included *L. caperata* in it. Since, however, this species does not in many respects possess the characters described by Hall and Sutton we must remove it at any rate into a subgenus, and for this subgeneric group of *Productella* the name *Whidbornella* is proposed, the characters of which are given below in the revised definition of this species which is chosen as the genotype. At least one other subgeneric group of the genus can also be recognized from the Upper Devonian (see sequel).

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[1] References are cited in the Bibliography which will appear at the end of the article.

Paeckelmann (1931) has discussed the differences between *Productella* and *Strophalosia*, and none of the subgenera or allied genera of the latter can be regarded as identical with *Whidbornella*. But if we follow Sutton's definition of *Strophalosia* (1938, p. 539) we should put *Whidbornella* as a subgenus of it rather than of *Productella*. Licharew (1936, pp. 126–9) has given a valuable examination of the differences between *Strophalosia* and the various groups or subgenera of *Productus*, but he does not allude to Devonian species.

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[1] Shimer (1926, p. 37) records this species from the Devonian.

Subgenus : WHIDBORNELLA nov.

Productella (*Whidbornella*) *caperata* (Sowerby)

The species from North Devon which Sowerby described and figured (1840, pl. liii, fig. 4) as *Leptaena caperata* has been generally considered to be identical with *Orthis productoides* Murchison (1840, p. 254, pl. ii, figs. 7a–c) from the Bas Boulonnais, and as Murchison's name has the priority of a few weeks Sowerby's specific name was dropped, but it has been revived by Paeckelmann (1931). Both Davidson (1868, p. 97, pl. xix, figs. 13–17) and Whidborne (1897, p. 175, pl. xxi, figs. 6–11) referred the species as interpreted by them to the genus *Strophalosia*, as did De Verneuil (1845, p. 283), Toll (1889, p. 26), Peetz (1901, p. 58), Loewe (1913, p. 25), and Leidhold (1928, p. 23), but Nalivkin (1930, p. 39) put it in the genus *Productus*. Hall and Clarke (1893, p. 317) included it in the genus *Productella* Hall, of which the genotype as above mentioned is *Productus subaculeatus* Murchison (1840, p. 255, pl. ii, fig. 9a–c), and Nalivkin (1930, p. 39) mentioned it as only a variety of that species under his description of *P. speciosus* Hall which is now usually put in *Productella*. Both *S. productoides* and *P. subaculeatus* were founded on specimens from the Upper Devonian of the Bas Boulonnais, and if we turn to Murchison's original description of the former and his figures of the French type and compare them with Sowerby's and Phillips' (1841, p. 38, pl. 23, fig. 98) descriptions and figures of *L. caperata* and with the abundant material in the Whidborne collection from the Pilton beds we cannot fail to be struck by the many points of difference. Whidborne (op. cit.) found some difficulty in defining the specific characters of *S. productoides*, but while attributing to it much variability he recognized that Davidson and others had included it in more than one species, as was more recently emphasized by the present author (1922, p. 38).

The most recent discussion on the subject with an emended description of Sowerby's species *L. caperata* has been given by Paeckelmann (1931, pp. 62–6, t. 2, figs. 6–8 ; t. 3, figs. 1–4) based on specimens from the Etroeungt stage in Germany, and he has rightly separated it from *S. productoides* (Murch.) as used by Whidborne, and has given an emended definition of its characters with a description of a new variety *radiata* (1931, p. 67, t. 3, figs. 6–11) which he suggests may correspond with Whidborne's *Productus scabriculus* (see postea). It is important to quote here Murchison's original definition of *Orthis productoides* which is as follows :—

" Semicirculaire, valve dorsale convexe, couverte d'épines nombreuses longues étroites, couchées et disposées irrégulièrement sur toute la surface ; charnière droite ; area triangulaire très surbaissée ; valve ventrale concave suivant les sinuosites de l'autre valve et ornée de plis rugueux irreguliers et subtransverses ; charnière droite, area très étroite et à peine la moitié de l'area dorsale. L'ouverture occupe le mileu d'un petit renflement placé a l'extrémité du crochet. Hauteur de la coquille 20 mm. ; largeur 23 mm. ; bombement de la valve dorsale 7 mm."

The spines on the surface of Murchison's figured type from the Bas Boulonnais seem to be much finer and more widely spaced and the concentric rugae on the postero-lateral areas (ears) much less developed than in Sowerby's *L. caperata* ; there is also an apparent absence of cardinal spines. Murchison's species indeed seems more like *Productella spinulicosta* Hall from the Chemung group of New York and from the Kuznetzk basin (Peetz, 1901, p. 53), especially resembling one figure of a specimen (Hall, 1867, pl. 23, fig. 35) from the Marcellus shales which Hall regarded as close to his species *P. shumardiana*.

Sowerby's definition of the British form *L. caperata* was as follows :—

" Half elliptical, very convex, concentrically wrinkled, spinose ; margin not much deflected ; one valve very convex, the other about equally concave ; hinge-line rather longer than the width of the shell ; spines adpressed, those near the hinge-line very long. The concentric rugae are lost towards the centre of the shell. *Locality* : abundant near Barnstaple and Petherwin, also in New Ilfracombe Road near Barnstaple. This species a good deal resembles *L. scabricula* (M.C. t. 69, fig. 1), but is well distinguished by the numerous concentric rugae and the smallness of its spines."

Davidson (1865, pl. xix, fig. 13) reproduced Sowerby's figure of *L. caperata* as the first example of *Strophalosia productoides*, but his description of the species embraces other British forms (as above stated) which cannot be retained in the same species, and it is therefore of little value. It is important to note that in Davidson's figure of the group of specimens containing Sowerby's types and occurring as casts in " Brown Grits " from Croyde there is a thin median septum shown in the right hand lower example of apparently the interior of a brachial valve such as is seen in one of Whidborne's unfigured specimens on the same slab of rock as " *Camerotoechia* " *partridgiae* (1897, pl. xix, fig. 13). No mention of this septum is made by either Sowerby or Davidson.

Phillips (1841, p. 58) gave the following somewhat different and fuller definition of *L. caperata* :—

" Oblong, semi-elliptical, hinge-line extended to a width rather exceeding that of the rest of the shell. Lower valve extremely and uniformly convex, the other rather concave. Surface concentrically wrinkled, most distinctly so on the sides and auriform extensions of the hinge ; longitudinally undulated on all the middle parts by the elongated bases of numerous slender spines. Hinge-line ornamented by long slender spines."

McCoy (1854, p. 388) gave another definition of the species, but he combined the characters of *Leptaena membranacea* Phill.

There are several important omissions in both of these quoted descriptions of the species. Firstly, there is the presence of hinge-areas on both valves ; secondly, the presence of a pair of small teeth in the pedicle-valve and of a pair of large flabellate feebly impressed divergent diductor muscle-scars with a pair of smaller adductor muscle-scars between them ; and thirdly, the presence in the brachial valve of a short bilobed cardinal process and median septum. Wulff (1923, p. 48) mentions both the cardinal process and median septum in his description of *S. productoides* from the Fammenian of the Aachen area, but Whidborne (op. cit.) does not allude to these characters, though some of his specimens exhibit them in spite of their generally poor state of preservation. But he like others included several distinct species under the one designation *Strophalosia productoides*, and he did not separate Sowerby's *L. caperata*, nor give any detailed description of the variability of the species which he supposed to have existed. His first figured example (1897, pl. xxi, fig. 6) which he ascribes to *S. productoides* is quite unlike Murchison's figure or description of that species, and does not even belong to the same genus or subgenus (see below under *P. goergesi*). McCoy (1854, p. 388) described *L. caperata* and mentioned the presence of a median septum and hinge-areas, but did not allude to *S. productoides*, apparently regarding them as distinct. The confusion thus caused by the various interpretations of the species *Orthis productoides* Murchison, if *Leptaena caperata* Sowerby and *Leptaena membranacea* Phillips are included, was commented on by the present author in recording the last named species from the Pamirs (1922, p. 87, pl. xiii, figs. 22, 22a) where it occurs in the Upper Devonian associated with other species of *Productella*, some of which are closely allied to Murchison's *Orthis productoides* and to several American species of the genus *Productella* occurring in the Chemung and Hamilton formations.

The following new and precise definition of Sowerby's species *L. caperata* sens.str. based on specimens from the type locality and horizon is therefore necessary and by it the points of difference from the typical " *Strophalosia* " *productoides* are clearly brought out :—

Shell unattached, subquadrate to semi-elliptical, widest along hinge-line ; cardinal angles subrectangular to subacute, often somewhat produced and subauriculate ; hinge-line straight, rather greater than the width of the shell, provided with several long straight slender spines horizonally directed back and nearly at right angles to it. Pedicle-valve moderately convex, but with more or less flattened large triangular postero-lateral cardinal areas or ill-defined ears ; umbo small, low, inconspicuous without cicatrix of attachment ; hinge-area small, triangular, nearly in plane of valve. Surface of valve mostly covered with closely placed rather stout elongated recumbent spines frequently overlapping and arranged in more or less longitudinal lines but not forming continuous costellae ; ears undefined, somewhat depressed, without spines but crossed by numerous regular narrow concentric rugae meeting the hinge-line at right angles. Brachial valve gently concave, with similar spinose ornamentation and flattened ears concentrically rugose ; hinge-area narrow, linear ; umbo small, low, inconspicuous. Interior of pedicle-valve with pair of small short teeth, and pair of weakly marked large flabellate divergent diductor scars about one-third the length of the valve, their bases separated by a small short ridge, and having a pair of small oval adductor scars between them. Interior of brachial valve with short bilobed cardinal process directed backwards and projecting above hinge-line, and with a thin median septum extending about half the length of the valve, and a pair of curved subcircular divergent brachial ridges arising from near the anterior end of the septum. [There is no evidence that the shell was attached as in typical *Strophalosia*.]

A typical example of the internal cast of a pedicle-valve showing the hinge-area, teeth, muscle-scars, and ornamentation of the surface is depicted by Whidborne in his figure 10, pl. xxi, representing a specimen [H. 275] from Poleshill. There was no brachial valve of the species figured by him, but as mentioned above there is on the slab of rock containing one of his figured examples of "*Camarotoechia*" *partridgiae* Whidborne (1897, pl. xix, fig. 13) an interior showing the cardinal process and median septum, and there is another but unfigured specimen in his collection from Pilton showing the septum and brachial ridges.

From the foregoing description of the characters of *P. caperata* we see that there are many points of difference from the genotype of *Productella* (*P. subaculeata* (Murchison)) of the Bas Boulonnais (1840, p. 255, pl. ii, figs. 9a–c) and also that it can hardly be put in the genus *Strophalosia s.str.* of which the genotype is *Orthis excavata* Geinitz of the Permian, though in many respects it resembles species commonly referred to that genus. The relations between *Productella* and *Strophalosia* on the one hand and *Productus* on the other were remarked by Hall and later by many other palaeontologists, especially by Paeckelmann (1931, pp. 51–62), but *L. caperata* seems to be intermediate between them sharing the characters of both. With regard to the specific affinities of *P.* (*Whidbornella*) *caperata* we may observe its close resemblance in most respects to *P. hirsuta* Hall (1867, p. 166, pl. 24, figs. 17–29) of the Chemung formation which has also been recorded from the Pamirs (Reed, 1922, p. 86, pl. xiii, fig. 15) and to *P. millespinosa* Girty (1915 (2), p. 14, pl. i, fig. 5) of the Boone Limestone, and we may probably refer *P. hirsuta* to the subgenus *Whidbornella.*

It is curious that Dehée (1929) does not mention the species or *S. productoides* in his account of the brachiopods from Etroeungt which include several of the other Pilton species (see below).

As regards the other specimens included by Davidson (1866, pl. xix, figs. 14–17) in *Strophalosia productoides* (Murch.) we may observe that *Leptaena laxispina* Phillips (1841, p. 59, pl. 25, fig. 99) which was re-figured by Davidson (op. cit., fig. 15) as well as the other example figured by him (figs. 16, 16a) are more like *P. subaculeata* (Murch.), while his fig. 14 of a specimen from Croyde Bay can hardly be regarded as identical with *P.* (*Wh.*) *caperata* as above defined. His fig. 17 belongs to *P. fragarina*, according to Whidborne (1893, p. 155, pl. xvii, figs. 10, 11).

We may here note that the figure which Whiteaves gives (1889, p. 112, pl. xv, fig. 2 ; 1891, p. 216) of a shell from the Athabasca River, Canada, as belonging to *Strophalosia productoides* is not like *P.* (*Wh.*) *caperata* or *P. subaculeata.* The Chinese brachiopod which Mansuy (1912, p. 52, pl. viii, figs. 5a–d) described as *Strophalosia productoides* and Grabau (1931, p. 43, pl. ii, fig. 5 ; pl. iii, figs. 28–30 ; pl. iv, fig. 19 ; pl. v, figs. 2–3, 7–11) as *Productella productoides* var. *sinensis*, seems to be also quite distinct from the British Upper Devonian species above described, and neither of the mutations described by Grabau nor the two varieties of the species recognized by him bear much resemblance to Murchison's type. For all of them are more or less transversely semicircular or subelliptical in shape, and have a hinge-line less than the width of the shell and a completely distinct ornamentation, the concentric rugae or laminae being over the whole surface and the spines mostly arranged on them ; cardinal spines also appear to be absent.

Productella (*Whidbornella*) *caperata* (Sowerby) var. *radiata* Paeckelmann

Paeckelmann (1931, p. 67, t. 3, figs. 6–11) has described a variety of

P. caperata from the Etroeungt stage under the above name and would doubtfully place in it all of Whidborne's specimens referred to *Productus scabriculus* (Mart.). But we can only regard one [H. 279] of them (1897, pl. xxi, fig. 12) as referable to it. The distinguishing feature is that the recumbent pustular spines of the typical form of *P. caperata* have become more or less fused longitudinally so as to produce radial costellae. In this specimen we can see that the cardinal process is trilobed near the base.

Productella (*Whidbornella* ?) *membranacea* (Phillips) var. nov. *piltonensis*

The shell [H. 276] which Whidborne figured from Poleshill (1897, pl. xxi, fig. 7) and included in his series of examples referred to *Strophalosia productoides* differs from the typical *P.* (*Whidbornella*) *caperata* by the shorter, smaller, finer, and more numerous and closely placed spinules on the surface which become small tubercles towards the margins, and by the presence of connecting concentric undulating or zigzag small narrow rugae which are specially developed on the lateral portions of the valves ; the concentric postero-lateral rugae are also much less strongly marked than in the type form of the species and occupy a smaller and less definite area on each side. The other specimen [H. 274] figured by Whidborne (op. cit., pl. xxi, fig. 9) from Pilton consisting of the right half of one valve showing the long cardinal spines may belong to the same variety, but it is less well preserved as regards surface ornamentation. From *Leptaena membranacea* Phillips (1841, p. 60, pl. 25, fig. 101), the type of which comes from Pilton, the less transverse shape of the above described variety of *P.* (*Wh.*) *caperata*, the more numerous spinules, the much reduced development of concentric undulating narrow rugae and the absence of radiating impressed lines on the surface of the shell are sufficient distinguishing features, but it seems more allied to Phillips' than to Sowerby's species.

It may be mentioned that Holzapfel (1895, p. 297, t. 12, fig. 12) held that *L. membranacea* was a species distinct from *S. productoides*, but he put it likewise in the genus *Strophalosia*, whereas it may be included in *Productella*, but it seems to be much like the genus *Chonetipustula* as defined by Paeckelmann (1931, p. 31). A fragmentary example of the typical *P. membranacea* showing the impressed fine radial lines occurs in the Whidborne collection from Paws Hill. The author figured a good example of it from the Upper Devonian of the Pamirs (1924, p. 87, pl. xiii, figs. 22, 22a). The internal characters of this species are unknown.

Productella (*Whidbornella?*) *membranacea* (Phillips) var. nov. *multipustulata*

This variety which is represented in the Sedgwick Museum by several well preserved specimens [H 1271] from Barnstaple differs from *P. caperata* by its transversely sub-elliptical shape and by the hinge-line being rather less than the width of the shell ; the posterior half or three-fourths of the surface of the pedicle-valve is also occupied by closely-placed rather coarse tubercles or pustules which become small short recumbent pustules irregularly but closely arranged in quincunx order towards the margins. In places the tubercles tend to fuse together laterally and to merge into the concentric rugae which cross the ears of the valves, thus forming a passage into the above described variety *piltonensis* in the style of the ornamentation. No cardinal or other spines can be detected on the specimens. The shape of the shell is more like *P. membranacea* (Phillips) as figured by Davidson (1866, pl. xix, figs. 18, 19) from South Petherwin, but is less transverse than Phillips' type, and the pustules are more numerous and the concentric rugae less developed while radial impressed lines are mostly absent.

Dimensions.—Length, 28 mm. ; width, 41 mm.

Productella (*Whidbornella*) *percostellata* sp. nov.

Whidborne's figure (1897, pl. xxi, fig. 8) of a pedicle-valve [H. 273] which he also attributed to *Strophalosia productoides*, though he noted the dissimilarity of the ornamentation, seems to belong to a distinct species. For it is covered with long narrow continuous costellae which do not bear spines or show any trace of having originated from the radial fusion of recumbent spines ; the depressed lateral cardinal regions or ears are devoid of costellae and only crossed by narrow concentric rugae, the marginal ones bearing a few spinose tubercles. The convexity of the body of the pedicle-valve is not well shown in Whidborne's figure, and the costellae are not represented as strong and continuous. But the cardinal spines and concentric rugae on the lateral cardinal regions as well as the shape of the valve resemble *P.* (*Whidbornella*) *caperata*, so that in spite of the apparent absence of spines or spinules on the body we may refer it to the same subgenus. For this new species from Pilton can be regarded as a further costellate stage of the variety *radiata* of *P. caperata* but differing in the complete radial fusion of all the recumbent spines. One of the figured specimens of *P. tullia* Hall (1867, p. 164, pl. 23, fig. 40) from the Hamilton formation of New York shows similar costellae developed in place of isolated or overlapping spines. An unfigured specimen of an internal cast of a brachial valve in the Whidborne collection from Pilton shows the subtriangular cardinal process trilobed at the base but broadening distally and dividing into two blunt processes grooved at their ends ; the median septum is thickest at its base and here seems to have a fine median groove, and is about three-fourths the length of the valve ; the posterior adductor scars are dendritic, but the anterior ones are smooth.

Productella (*Whidbornella* ?) *productoides* (Murchison) var. nov. *multirugata*

Shell small, somewhat flattened, semi-elliptical, as long as wide ; cardinal angles rectangular. Pedicle-valve gently convex in median posterior region, flattened elsewhere ; postero-lateral areas not marked off ; umbo small, rising a little above hinge-line ; hinge-area narrow, triangular ; whole surface of valve ornamented by numerous continuous narrow regular equidistant concentric rugae most distinct posteriorly, but becoming weaker in umbonal region, and by fine recumbent elongated spinules scattered over the whole surface but widely separated, being about three times their thickness apart, and arranged roughly in quincunx fashion ; hinge-line furnished with three widely spaced slender spines at right angles to it on each side of umbo.

Remarks.—This small specimen [H. 292] from Poleshill was considered by Whidborne to be a young individual of *Strophalosia productoides* (Murchison) (1840, p. 254, pl. ii, fig. 7) and was figured by him (1897, pl. xxi, fig. 11) as such. It differs from those specimens above described as *P.* (*Whidbornella*) *caperata* in the development of the concentric rugae over the whole surface of the valve instead of only on the flanks, and also in the wide spacing, delicate nature, shorter length, and small number of the spinules on the surface. It is more like the original *Orthis productoides* of Murchison than *P. caperata*, and resembles several American species of *Productella* from the Devonian, such as *P. spinulicosta* Hall (1867, pl. 23, fig. 35 non cet.), especially one from the Marcellus Shales (Hall and Clarke, 1892, pl. xvii, fig. 4), a species which as previously stated comprises the American shells usually referred to *P. subaculeata* (Schuchert, 1897, p. 318). But *Strophalosia rockfordensis* Hall and Clarke (1892, p. 353, pl. xvii A, fig. 1) from the Upper Devonian of Iowa seems most like it. The species from the Pamirs (Reed, 1922, p. 85, pl. xiii, figs. 10–14) named *P. baitalensis* may also be compared, and the specimen from the Frasnian of Almaden which Müller (1929, p. 254, t. 2, fig. 8) refers to *Productella subaculeata* (Murchison) seems to bear much resemblance to the above described Poleshill specimen judging from his description and figure.

Productella (*Whidbornella* ?) cf. *lachrymosa* (Conrad)

The imperfect specimen [H. 289] from Pilton which Whidborne figured (1897, p. 174, pl. xxi, fig. 1) as *Productus* cf. *subaculeatus* Murch. appears to resemble somewhat closely *Pr. hirsuta* Hall as figured by Prosser (1912, p. 547, pl. xxxii, figs. 7–9) from Ohio, and is quite distinct from Murchison's species. *P. lachrymosa* (Conr.) and its varieties *lima* and *stigmata* which Hall described from the Chemung formation of New York (1867, p. 172, pl. 25) and Nalivkin (1930, p. 41, t. ii, fig. 29) from Turkestan and the author from the Pamirs (1922, pp. 86, 87, pl. xiii, figs. 16–19, 20, 21) are specially comparable, but Whidborne's specimen is hardly perfect enough for a satisfactory determination. *P. lachrymosa* var. *marylandica* Clarke and Swartz (1913, p. 565, pl. 51, fig. 4) appears to be most like it.

Productella (*Whidbornella* ?) cf. *kayseri* Paeckelmann

Paeckelmann is of the opinion that Whidborne's second figured specimen [H. 290] from Fremington which he compared with *P. subaculeatus* Murch. (1897, pl. xxi, fig. 2) may belong to his new species *Productella kayseri* (1931, p. 60, t. ii, figs. 5a–c). But we may also draw attention to its resemblance to *P. subalata* Hall (1858, p. 500, pl. iii, figs. 10a–c) from the Devonian of Iowa, while the above mentioned variety *marylandica* Clarke and Swartz (1913, p. 565, pl. 51, figs. 4–9) of *P. lachrymosa* (Corn.) seems also to be somewhat like it. *P. fragilis* Belanski (1928, (2) p. 192, pl. xiv, figs. 15–17) from the Shellrock stage of the Devonian of Iowa which is considered to be nearly related to *P. subalata* (Hall) may also be compared. Whidborne's other specimen [H. 291] (fig. 3, pl. xxi) from Fremington is too poor for a satisfactory determination.

Subgenus : HAMLINGELLA nov.

Productella (*Hamlingella*) *goergesi* Paeckelmann, var. nov. *capillaris*

Shell transversely sub-elliptical, cardinal angles rounded ; hinge-line less than maximum width of shell ; margin of valves furnished with dense fringe of long slender hair-like radial spines which are straight except just below and at the cardinal angles where they are curved back, and longer than elsewhere ; hinge-line without any spines. Pedicle-valve moderately convex, with its surface covered with similar slender spines arranged in a somewhat irregular concentric manner ; umbo small, inconspicuous.

Dimensions.—[H. 456] Length, 26 mm. ; width, 48 mm. ; length of marginal fringe, 10 mm.

Remarks.—This specimen [H. 456] which seems to be a pedicle-valve is from " Laticosta Cove, Baggy ", and was figured by Whidborne (1897, pl. xxi, fig. 6) as his first example of *Strophalosia productoides* (Murch.), but it cannot be referred to that species. It seems to have some of the characters of *P. hystricula* Hall (1867, p. 178, pl. 26, figs. 1–8 ; Clarke & Swartz, 1913, p. 567, pl. li, figs. 16–19) from the Devonian (Chemung) of the United States, a species which is put by Hall & Clarke (1892, p. 316) in the genus *Strophalosia.* But we cannot fail to recognize its resemblance to Paeckelmann's species, *Productella goergesi* (1931, p. 56, t. 2, figs. 1, 2 ?) from the Etroeungt stage near Ratingen, a species which Paul (1937, p. 435) states he has also found near Barnstaple as well as in France and Belgium. But Paeckelmann does not show or mention that there is any fringe of hair-like spines round all the margin of the shell, and the surface ornamentation of his species appears to be somewhat different, so that we may regard Whidborne's specimen as at any rate a variety. For some reason Whidborne only figured the posterior part of the shell, thereby omitting the circum-marginal fringe as well as failing to show the shape of the shell. We can hardly put it in the same group of species of *Productella* as the genotype nor in the subgenus *Whidbornella*, and it seems almost to deserve generic rank, but until better specimens are obtained we may designate it provisionally as a separate subgenus with *P. goergesi* Paeck. as the type and propose for it the name *Hamlingella* after Mr. J. G. Hamling whose collection of Upper Devonian fossils was much used by Whidborne in his work. A similar spinosity is present in *Productus newberryi* Hall (Hall & Clarke, 1892, pl. xviii, fig. 1) from the Waverly Sandstone.

(*To be continued*)

CORRESPONDENCE

THE CLEVELAND AXIS

Sir,—It would be impossible to maintain all the generalizations and conclusions put forward in an article on Mesozoic and Cainozoic folding written ten years ago, some of which have been proved wrong or modified by the subsequent borings for oil in many parts of England. But one of the axes about which there is least need to modify what was written before this recent flood of illumination still seems to me to be the Cleveland Axis. It was contended that this anticline was not elevated in Jurassic times, at least so far as can be judged from the evidence of the rocks involved, which do not include anything later than the Bathonian.

Dr. Rastall, in an article with the above title (*Geol. Mag.*, lxxx, p. 30), quotes a statement of mine to this effect (*Rept. XVI Int. Geol. Congress*, Washington, 1933) and comments that " as regards the Cleveland axis this sweeping generalization requires a good deal of qualification,"[1] and after reviewing all the Jurassic rocks of North Yorkshire from Lias to Corallian inclusive, concludes " From a consideration of all the foregoing facts, it is hardly too much to say that Arkell's statement is really only true for the Lias."

In a passage immediately before that quoted by Dr. Rastall, I made it clear how I defined the axis : " The Cleveland anticline involves the Lower Oolites and Lias of Cleveland, and runs out to sea as a well-marked arch in the Lower Lias of Robin Hoods Bay. Its trend is approximately east-west, along the centre of the Yorkshire ' Basin ' . . ." Since the Oxfordian and Corallian rocks do not now extend across the axis, all that Dr. Rastall says about them is irrelevant.

There remain, therefore, only the Lower Oolites in dispute. About the thin Dogger and immediately subjacent strata Dr. Rastall and Dr. Hemingway have found out a great deal of detail that was not available ten years ago. I have not at present time to comb their recent papers to ascertain whether their work demonstrates the existence of pebble-beds or non-sequences in these rocks *as they pass over the axis* : i.e. restricted to the line of the axis and contrasting with the developments on either side ; or of facies changes attributable to movement of the axis because restricted to it or bounded by it. Dr. Rastall does not claim any such conclusive evidence of differential movement of the Cleveland axis in the paper now in question, from which it may perhaps be concluded that he knows of none ; though possibly the detail which he says he cannot now discuss may provide the evidence.

As to the Estuarine Series, it is misleading to quote the deltaic facies as evidence of differential movement along the Cleveland axis in Jurassic times. The deltaic facies is a palaeogeographical effect and the whole Yorkshire basin is involved equally. In Bathonian times the facies even extended far beyond the Market Weighton axis into south-Humbrian England.

It would appear that Dr. Rastall has missed the essential drift of my remarks, which were designed to distinguish between epeirogenic movements and the more localized synorogenic movements—to use a convenient term of Stille's for those uplifts which took place, usually along old anticlinal or faulted lines, during times of distant orogenic activity (*Grundfragen der Vergleichenden Tektonik*, 1924, p. 16). In order to emphasize my meaning, I may perhaps be allowed to quote again from the 1933 paper and italicize the critical passage of the sentences referring to the Cleveland anticline. " The formations involved do not show any noticeable change of facies or attenuation *as they pass over it*."

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[1] When does a generalization become sweeping "? When one disagrees with it ?

I should be the last to deny that the general subsidence of the Yorkshire basin in Jurassic times was interrupted by oscillations. To what extent they became expressed in the sediments would depend mainly upon the depth of water and the nature and quantity of sediment supplied. Thus the relative uniformity and continuity of the Lower Lias is probably only apparent, due to greater depth of water, which in turn was due to difference in the ratio between rate of subsidence and rate of sedimentation as compared with later periods. The Yeovilian and Aalenian, in which Dr. Rastall finds notable signs of instability in the Yorkshire basin, are characterized by " abnormal " sedimentation nearly everywhere (see *Jurassic System in Great Britain*, 1933, fig. 30, facing p. 165). Intensive study of any formation will lead to the discovery that it is far less uniform than was previously supposed. The Cornbrash is a striking instance (*Quart. Journ. Geol. Soc.*, 88, 1932, pp. 141–8). My object was to examine to what extent these effects were localized along particular axes and could be separated from the general epeirogenic effects. I know of nothing which necessitates modifying the conclusions reached in respect of the Cleveland axis.

W. J. ARKELL.

CUMNOR, OXFORD.
2nd April, 1943.

I criticized Dr. Arkell's original statement because he wrote that the *Jurassic* rocks pass unchanged over the Cleveland axis. He now says (incorrectly) that nothing later than the Bathonian is involved. After this, detailed discussion seems unprofitable. I will, however, add that the pebble beds of the Yeovilian-Aalenian unconformity, exactly on the central line of the axis, now being worked out, give evidence of extensive and deep erosion at that time.

A generalization may be described as sweeping when, as in this instance, it brushes aside all the facts that are inconsistent with it.

R. H. RASTALL.

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Pimlicocrinus gen. nov. and two new species of *Amphoracrinus* from the Carboniferous Limestone

By JAMES WRIGHT

(PLATES III—VI)

INTRODUCTION

IN a recent paper (*Geol. Mag.*, lxxix, 1942, 272), a single specimen from Coplow Knoll, Clitheroe, which differed from the commoner forms found there, was referred to the genus *Amphoracrinus* under the name of *A. clitheroensis*. Some time after sending this paper to the editor I found in my collection a smaller specimen belonging to the same species and still later another one, together with seven specimens belonging to a distinct though closely allied species. This additional material shows that both species differ in several respects from *Amphoracrinus* and the new genus *Pimlicocrinus* is now proposed for their reception.

Amphoracrinus includes at least six British and American species. The latter were described by Wachsmuth and Springer in 1897, the former by various authors in the earlier part of last century. The British species hitherto recognized in the literature are only three in number but it cannot be said that they are properly understood at the present day. In fact, it has long been a subject of reproach to British palaeontologists that for nearly a century now little or nothing has been done to extend our knowledge of *Amphoracrinus* as well as of its associated genus *Actinocrinus*, specimens of which occur in large numbers in the Carboniferous limestones of Lancashire, Yorkshire, and elsewhere in England and Ireland. While it is easy to distinguish one genus from the other, the worker among these crinoids often finds great difficulty in determining the species to which many of the specimens should be assigned. There are several reasons for this: (1) the condition of the specimens themselves occurring as they generally do as more or less imperfect calices only; (2) the great variation in shape exhibited by the specimens; and (3) the dearth of literature dealing with the British species. The last named is now totally inadequate for the discrimination of the various forms; hence a revision of both *Amphoracrinus* and *Actinocrinus* as they occur in this country is much to be desired. Such a revision would of course be a laborious task at any normal time, with free access to all type and other specimens in our museums but is impossible under the present disturbed conditions when facilities of this kind are not available. In an attempt to get some light on the subject I have recently gone over all my collection of both genera from the Clitheroe area, amounting to several hundred specimens. So far attention has mainly been confined to *Amphoracrinus*, and this has resulted in the discovery of the two new species now here referred to

Pimlicocrinus. Two new species of *Amphoracrinus* have also been found and these are briefly described herein. At the same time it has to be admitted that the study of the Clitheroe specimens of *Amphoracrinus* has been somewhat disappointing. Hopes were entertained that it would be possible to describe the various forms with greater precision and in more detail. Owing, however, to the impossibility of getting access to the figured specimens of the three chief British species, viz. *A. gilbertsoni*, *A. atlas*, and *A. olla*, especially of the first-named which must be regarded as the genotype, or to compare the Clitheroe specimens with a large series from other localities in England and Ireland this project has in great part had to be abandoned. Meanwhile some of the more prominent forms have been prepared and photographed and rather than lay them aside indefinitely a few have been selected and are now illustrated on the accompanying plates. It is hoped that these along with the following notes may prove helpful to any future investigator. The specimens themselves have been collected over a period of thirteen years, prior to 1939, during annual visits to the Clitheroe region.

Here I must express my thanks to Mr. L. Bairstow of the British Museum, Mr. A. G. Brighton of the Sedgwick Museum, Cambridge, Dr. H. C. Versey of Leeds University and Mr. R. Wagstaffe of the Yorkshire Museum, York, for kind help in trying to trace the whereabouts of the figured specimen of *Amphoracrinus gilbertsoni* (Phillips). I am specially indebted to Mr. Wagstaffe for sending me two specimens which he believes to be contemporary topotypes of *A. gilbertsoni* (Phillips). These are noted later. My thanks are also accorded to Mr. Stanley Westhead, of Clitheroe, for the loan of specimens, two of which are illustrated on Pl. IV, figs. 12–14.

AMPHORACRINIDAE Bather

Amphoracrinus Austin

The specimens illustrated on Pls. IV, V, and VI are typical of some of the more prominent forms which occur in the Clitheroe area. Before dealing with them it is necessary to take note of all the British species which so far have been figured or described and are now regarded as belonging to *Amphoracrinus*. These are as follows :—

1826, Cumberland, *Amphora* (2nd. Species), pl. A, fig. at foot ; pl. C, figs, 1, 3, 4, 22.
1836, Phillips, *Actinocrinus gilbertsoni* Miller MS., pl. iv, fig. 19.
1838, Goldfuss, *Melocrinites amphora* Goldfuss, pl. 31, fig. 4.
1843, Austin, *Actinocrinus crassus* Austin (not figured).
„ *granulatus* Austin (not figured).
1845, Portlock, *Actinocrinites amphora* (Gilbertson) = *Melocrinites amphora* Goldfuss and *Actinocrinus gilbertsoni* ? Phillips, pl. xv, figs. 4, 5, 6.
1848, Austin, *Amphoracrinus* gen. nov. (not figured).
1855, McCoy, *Actinocrinus gilbertsoni* (Miller) (not figured).
„ (*Amphoracrinus*) *atlas* McCoy, pl. 3D, fig. 5.
„ (*Amphoracrinus*) *olla* McCoy, pl. 3D, fig. 6.
1862, „ *amphora* Gilbertson = *Melocrinites amphora* Goldfuss and *Actinocrinus amphora* Portlock (not figured). (Preface dated 1844.)
1865, Rofe, *Amphoracrinus*, pl. viii, fig. 2.
1875, Baily, *Actinocrinus amphora* (Goldfuss), pl. 36, fig. 10.

In addition to the above, de Koninck (1842, pl. G, fig. 2) illustrated a specimen referred to *Actinocrinus gilbertsoni*, but this is not an *Amphoracrinus*.

When the Austins (1848, p. 206) proposed the genus *Amphoracrinus* " to embrace forms which differ from the true *Actinocrini* both as regards the position of the mouth [anus] and the number of plates comprising the calcareous skeleton " they included in the genus *Actinocrinus gilbertsoni* (Phillips), *A. crassus* Austin, *A. granulatus* Austin and a fourth species not named. *A. crassus* and *A. granulatus* were originally described by the Austins in 1843, but were never figured and owing to the terminology then employed the descriptions by themselves do not enable us to identify the species. It is hoped that the Austins's specimens will be dealt with some day. As for *A. gilbertsoni*, this species was described by Phillips in twelve words (1836, p. 206, and pl. iv, fig. 19). The name seems to have been a manuscript name given by Miller, but the species was not described or figured by him. Wachsmuth and Springer (1897, p. 586) in describing the American species of *Amphoracrinus* regard the *Amphora* (2nd species) of Cumberland, *Melocrinites amphora* Goldfuss and the same species under this and other names mentioned by Portlock and McCoy, as synonyms of *Amphoracrinus gilbertsoni*. This seems to have been the generally accepted opinion, although one notes that McCoy (1855, p. 120), in describing *A. gilbertsoni* without figures, points out what he considers to be certain differences between it and *A.* (*Melocrinites*) *amphora* Goldfuss, chiefly the length and breadth of the radials and brachials and the finer sculpturing on *A. gilbertsoni*. He apparently regarded *A. amphora* Goldfuss as a distinct species. Rofe (1865, p. 245), in referring to the passage of the arm grooves into the tegmen in different genera, says " The species in which these passages were first observed by me is *Amphoracrinus rugosus* ". I can find no further reference to this species, which may have been an MS. name given by Rofe himself. On the plate accompanying the paper Rofe figures a specimen (pl. viii, fig. 2) under *Amphoracrinus* only. No species is mentioned, but this figure has a remarkable resemblance to a form which occurs at Knoll Wood and Coplow and will be noted later. Baily (1875, pl. 36, fig. 10) figures a specimen referred to *A. amphora* Goldfuss, but it differs considerably from the figure of Goldfuss, the dorsal cup being rounder with the tegmen proportionally less in height and much rounded and swollen.

Returning to *A. gilbertsoni* : Mr. Bairstow is unable to locate Phillips's figured specimen of this species in the British Museum, nor is it in the Sedgwick Museum at Cambridge. The types of *A. atlas* McCoy and *A. olla* McCoy belong to this museum but are stored away at present. Dr. Versey, of Leeds University, informs me that there is a chance of Phillips's type of *A. gilbertsoni* being in the Leeds City Museum but the geological collection there is not accessible at present. The specimen has not so far been found in the Yorkshire Museum, at York, Mr. Wagstaffe, the Keeper, having made a special search for it. From all this it will be seen that no really satisfactory description of the Clitheroe specimens can be given at this stage, the chief obstacle being the uncertainty of fixing the precise identity of *A. gilbertsoni* among them. Phillips's figure of this species is rather poor (1836, pl. iv, fig. 19). It is a posterior view and from it one gathers that the cup is very shallow, much shallower than in any of the figures of Cumberland, Goldfuss, or Portlock. This may be somewhat illusory since the specimen seems to be tilted to show the plates all round the cup. The tegmen is high and somewhat lobed with five spiniferous oral plates at the summit and anal opening in front in the excentric position. Of course, features like these are in general more or less common to all the figures of Cumberland, Goldfuss, and Portlock, but one notices a considerable variation in the shape of the calyx in all the figures, no two being exactly alike. One might hazard the opinion that the figure of Phillips, although distorted, has more resemblance to that of Goldfuss than both of these have to the figures of Cumberland and Portlock. Then Portlock's figure, which shows a somewhat low cup and relatively low tegmen, does not quite agree with the figures of Cumberland, where the cup is deeper and tegmen relatively high and more rounded. The tegmen is prominently lobed in the figure of Goldfuss, presumably also in the specimen of Phillips, but this character is not so apparent in the figures of Cumberland and Portlock. If it is correct to regard all these figures as representative of one and the same species it is obvious that there is a good deal of variation in the calyx of *A. gilbertsoni*. One may doubt, however, that all the figures do represent one species only. As regards *A. atlas* McCoy and *A. olla* McCoy (1855, pl. 3D, figs. 5 and 6) the former species has a very high and somewhat rounded tegmen. Although rare, it is possibly represented at Clitheroe. I have, however, never seen any specimen which would agree with McCoy's figure of *A. olla*. This figure shows a swollen and rounded cup and a greatly constricted tegmen. McCoy says the species is very common in the Carboniferous Limestone of Derbyshire. The figure lacks details of the summit of tegmen, the specimen apparently being damaged here, but the constriction of the tegmen if correctly drawn does not appear to agree with the more usual characters of *Amphoracrinus*. These characters may be summarized thus: the dorsal cup may be low or high, rounded or expanding, the tegmen is usually higher but in some forms about the same height as, or even less than, the cup; the tegmen may also be somewhat tapering towards the summit and prominently lobed or it may be inflated with a rounded top and somewhat straight sides with or without marked lobes. On the summit of the tegmen there is usually a more or less flat area which is occupied by five prominent oral plates, four of these being arranged in the form of a semicircle. Within the curve of the semicircle and occupying the central part of the summit is the fifth plate, often larger than the others, with the anal tube rising in front of it in an excentric position. In some American species the orals are strongly spiniferous, the spines being long and thorn like. In the Clitheroe forms the orals may also be spiniferous but the spines are apparently shorter and in many cases worn off. Even so the orals are always large and conspicuous plates and at once attract the eye. In the posterior area of the cup the anal plate X rests on the basals and cuts the ring of the radials. It is usually surmounted by two plates only, but in certain American species three have been noted, the middle one being wedge shaped. Wachsmuth and Springer's statement (1897, p. 587), that in English species there are always two plates occupying this position, holds good for the majority of specimens but is rather too sweeping. Among 60 specimens from Coplow four show three plates above the anal X, the middle of which is fairly wide where it joins the basals. Three of these specimens are shown on Pl. V, figs. 5, 8, and 12. One of the Knoll Wood specimens also shows this type of structure (Pl. V, fig. 7). None of the Bellman specimens exhibit it. Other than the brachials which form part of the cup, none of the Clitheroe specimens show any trace of the arms. All the calices are more or less broken at the free arm bases. The brachials up to the first secundibrach, and occasionally up to the second secundibrach, are included in the cup. As so far observed in the Clitheroe specimens the first secundibrach is not always axillary.

The Clitheroe Specimens

The material examined consists of 162 calices or thecae. Ninety-three are from Bellman Quarry, 60 from Coplow Knoll, and 9 from Knoll Wood, Newton in Bowland. Coplow is regarded as of C_1 age, Bellman and Knoll Wood as of C_2 age (Parkinson, 1936). At Bellman the specimens were found in the crinoid limestone at the top of the section. At the time of my earlier visits it was comparatively easy to find specimens, but was more difficult in later years as no fresh exposures were available. Perhaps the most remarkable fact about this horizon is the great abundance of specimens of *Amphoracrinus* contrasted with the total absence of *Actinocrinus*. The latter genus is represented by large numbers of specimens at Coplow. They occur throughout the section and are associated in some layers with specimens of *Amphoracrinus*. The total numbers, however, of *Amphoracrinus* given above—93 from Bellman and 60 from Coplow—are not a good indication of their relative abundance at the two localities. It is not an overstatement to say that had the Bellman exposure always been workable and the same number of days spent on it as at Coplow the total from Bellman would have been multiplied many times. The absence of *Actinocrinus* at Bellman appears to indicate that this genus died out in this area before the deposition of the Bellman crinoid limestone and its place as the dominant element in the crinoid fauna was taken by *Amphoracrinus* which apparently reached its acme at this stage. It is, perhaps, therefore not surprising that there is a greater variation among the Bellman specimens compared with those from Coplow. As to the condition of the specimens as a whole, some are crushed but the majority are well preserved. The anal tube is in most cases broken off. It is usually present in the small or young individuals, but is only partly preserved in a few adults. In size the specimens range from young examples less than 12 mm. in height to large mature specimens over 50 mm. in height, measured from the base of cup to the upper level of tegmen. In sorting them out the only criterion of value is the shape of the theca. This is somewhat variable although one might say that in a broad sense the majority of the specimens have a general resemblance to the figures of *A. gilbertsoni* already cited and there can be no doubt that they are all closely related. Among them, however, are several characteristic shapes which do not come within the range of any described species. Twenty-eight specimens belonging to two of these shapes are so distinctive that they are here assigned to two new species and described below. All the others, except two which are referred to *A. atlas* McCoy, are provisionally grouped under *A. gilbertsoni*, although there are forms among them whose precise specific relationships cannot at present be accurately defined. These are designated by numerals. The extent to which some of these forms may hereafter be regarded simply as varieties of *A. gilbertsoni* or as distinct species is a matter for further research. It is of course a handicap not having the figured specimen of *A. gilbertsoni* for comparison, but taking the figures already cited as a guide we may with some confidence sort out the majority of the specimens under the head of this species.

Amphoracrinus gilbertsoni (Phillips) species group

The specimens coming under this head number 132 in all. They are here arranged into three main series termed respectively Form I, Form II, and Form III. Details of their numbers at the different localities are noted below. Within each series the general shape of the theca is fairly constant but there is considerable variation in the relative heights of cup and tegmen. The specimens represent all stages in growth from young to large mature examples.

FORM I

Pl. IV, figs. 2–4, 8–10, 12–14; Pl. V, figs. 1–4, 6, 9, 13; Pl. VI, figs. 13–15.

In this form the cup is rather deep, conical in shape, on an average about twice as wide as high, with regularly expanding or occasionally slightly rounded outline. The tegmen is usually high and may be 1¼ to 1½ times higher than the cup. It is more lobed in some specimens than in others and tapers from the cup upwards to the flat area occupied by the orals which, on the anterior and lateral sides of most specimens of this type, form a rim round the summit. These shapes are exemplified by such specimens as are shown on Pl. IV, figs. 2, 8, 9, 10. The Bellman specimens show many modifications from these. In some the theca is stouter with tegmen relatively less high and this shape grades into others in which the tegmen is narrower at the top and is only about the same height as the cup. This last-mentioned shape also occurs at Coplow and a very pronounced form of it is exhibited by the Knoll Wood specimens, six of which are of this type (Pl. V, figs. 1–4). The extreme range of this shape is seen in a few large specimens from Coplow, one of the largest of which is illustrated on Pl. V, fig. 6. A specimen not unlike these Knoll Wood and Coplow forms is figured by Rofe (1865, pl. viii, fig. 2) and has already been alluded to. The tegminal plates above the fixed brachials are usually spiniferous. This seems to be a feature common to all specimens, but is more noticeable on some than on others. The spines are short and blunted. This also applies to the orals, but in a few cases the spines, although short, are sharp and pointed. Young specimens of Form I are shown on Pl. IV, figs. 12–14, and Pl. VI, figs. 13–15.

FORM II

Pl. IV, figs. 1 and 5 ; Pl. V, fig. 10.

This form differs from the preceding mainly in the shape of the tegmen, which is moderately high, but is somewhat broad and rounded at the top, the cup being deep and similar to Form I. The orals here do not form the rim of the summit of tegmen but are merged with the other plates of the rounded area. The type can be distinguished in small or young specimens. It occurs at Coplow only and two of the largest examples are shown on Pl. IV, figs. 1 and 5, and Pl. V, fig. 10. There is a possibility that this form may be regarded as a variant of *A. atlas* McCoy, but judging from McCoy's description and comparative measurements of his figure (1855, pl. 3D, fig. 5) this view does not at present seem justifiable. Of *A. atlas*, McCoy says, " The enormous size of the visceral portion above the arms (nearly three times the height of the cup) has suggested the specific name." None of the specimens here considered merit that description, the tegmen never exceeding more than 1½ times the height of the cup and the tegmen itself is always more rounded at the top. The cup also is deeper than in *A. atlas*.

FORM III

Pl. IV, fig. 11 ; Pl. VI, figs. 4, 8–12.

In this series are placed five comparatively small specimens, one from Coplow and four from Bellman. Although small they cannot be regarded as young specimens of Forms I or II (compare Pl. VI, figs. 4 and 12, Form III, with figs. 13 and 14, Form I alongside). As a matter of convenience they are at present grouped together, although it is not quite certain that they all belong to the same species. The cup here is low with tegmen high in proportion and markedly lobed. This is specially pronounced in the small Coplow specimen (Pl. VI, figs. 4 and 12) where the tegmen is about three times the height of the cup. The four Bellman specimens are larger. Two of them (Pl. IV, fig. 11, and Pl. VI, fig. 11) agree fairly well with the Coplow specimen as also does the third (not figured), but the fourth one (Pl. VI, figs. 8–10) has a somewhat broader cup and a tegmen composed of fewer and larger plates. None of these specimens agree with any of the figures of the authors already quoted or with any of the other Clitheroe specimens. After the present paper was written Mr. R. Wagstaffe, of the Yorkshire Museum, sent me two specimens of *Amphoracrinus*, which he believes to be contemporary topotypes of *A. gilbertsoni* (Phillips). Both specimens are small, one measuring about 25 mm. high and the other 19 mm. high. In both the cup is very low and tegmen about twice as high. Their general habitus is similar to the specimens grouped under Form III and I would place them here at present, not under Forms I or II.

Amphoracrinus atlas McCoy

Pl. IV, figs. 6 and 7.

This species is stated by McCoy to be rare in the Carboniferous Limestone of Bolland. So far, only two small specimens which seem referable to it have been found at Bellman. The cup is somewhat low and tegmen very high, about three times higher than the cup, with gently rounded top and not greatly lobed. The two specimens agree in these details with *A. atlas* and the general habitus also seems similar.

Amphoracrinus compressus sp. nov.

Pl. V, fig. 11.

A species with deep cup and low compressed tegmen less than height of cup ; tegmen rather flat on top and somewhat strongly lobed ; cup conical, expanding to IBr_1, where it is about three times the width of BB at column facet ; basal circlet moderately high, about half as high as RR ; areas between left and right posterior lobes rather wide.

Holotype.—J. W. Coll. No. 2418 (Pl. V, fig. 11).

Paratypes.—J. W. Coll. Nos. 2419, 2417.

Locality.—Knoll Wood, Newton in Bolland.

Dimensions of Holotype.—Height of theca over all 35 mm. ; height of tegmen 15 mm.

Dimensions of Paratypes.—No. 2419, height of theca over all 33 mm. ; height of tegmen 14 mm. No. 2417, height over all 27 mm. ; height of tegmen 12 mm.

Remarks.—This species differs markedly from any figured specimen of *Amphoracrinus* or from the forms noted above. Compared with these it at once attracts the eye by the extremely low tegmen which is in striking contrast to the usually high tegmen in other species of the genus. The deep cup and the width of the posterior area of the calyx also attract attention. All three specimens are from Knoll Wood. In the two smaller paratypes the low tegmen is even more emphasized than in the holotype.

Amphoracrinus turgidus sp. nov.

Pl. VI, figs. 1–3, 5–7.

A species with moderately deep expanding cup and inflated tegmen ; tegmen $1\frac{1}{4}$ to $1\frac{1}{2}$ times higher than cup, rather large flat area on top extending beyond the orals, abruptly truncated on posterior side, lobes prominent ; posterior area between left and right lobes rather wide.

Holotype.—J. W. Coll. No. 2412 (Pl. VI, figs. 5–7).

Paratypes.—J. W. Coll. No. 2413 (Pl. VI, figs. 1–3), Nos. 2414, 2415.

Locality.—Bellman Quarry, Clitheroe.

Dimensions of Holotypes.—Height over all, 38 mm. ; height of tegmen, 24 mm.

Dimensions of Paratype.—Height over all, 31 mm. ; height of tegmen, 20 mm.

Remarks.—Twenty-five specimens are assigned to this species. All occur at Bellman. In shape they are so distinctive that they cannot be confounded with any of the forms considered above. The holotype is the largest example. One of the paratypes, No. 2414, not figured, is the smallest and is only 26 mm. high. It is one of the few examples in which the ornamentation on the plates is well preserved. This is of the usua *Amphoracrinus* type, but is rather coarse. One of the chief characteristics of this species is that when viewed from the left or right lateral position the tegmen is more abruptly truncated on the posterior side than in other species of *Amphoracrinus*. This appearance is enhanced by the fact that the left and right posterior lobes are considerably produced and the area between is straight or even concave. Another distinctive feature is the large extent of the flat area on the summit of tegmen embracing the orals and adjoining plates. In some specimens the tegmen is relatively lower than in the holotype and the large flat area on the summit is more pronounced. The oral plates are conspicuous and large. The spiniferous character of these plates is well shown on the holotype. Short blunted spines are also present on a few of the adjoining plates which extend for a short distance over and down the left and right posterior lobes. The second or third plate above the fixed brachials is also spiniferous all round the calyx. The inflated nature of the tegmen is less noticeable on the anterior side where it has a more gradual slope. The cup is a little variable in shape. In most specimens the basals are somewhat flat and low in comparison with the radials and in the holotype and some other specimens the plates of the cup from the basals upwards swell out to the region of the fixed brachials where there is some overhang of the lobes. This feature is not quite so pronounced in the paratype shown on Pl. VI, figs. 1–3. The specimen figured by Baily (1875, pl. 36, fig. 10) and referred to *Actinocrinus amphora* Goldfuss has some resemblance to the present species but differs in its rounder cup and less inflated tegmen.

Statistics of Specimens

		No. of Specimens.
Coplow.		
Amphoracrinus gilbertsoni	Form I	45
„ „	Form II	14
„ „	Form III	1
		60
Bellman.		
Amphoracrinus gilbertsoni	Form I	62
„ „	Form III	4
„ *turgidus* sp. nov.		25
„ *atlas* McCoy		2
		93
Knoll Wood.		
Amphoracrinus gilbertsoni	Form I	6
„ *compressus* sp. nov.		3
		9

Total 162.

Pimlicocrinus gen. nov.

An Amphoracrinid with low dorsal cup; IIBr$_1$ axillary; brachial areas up to IIIBr$_1$ or IIIBr$_2$ included in cup; iBr few between short or extended lobes formed by fixed brachials and plates of tegmen; anal X surmounted by two plates; tegmen moderate to high in relation to cup; oral plates may be slightly larger than other plates of tegmen but not specially differentiated; anal opening at end of a short tube which is not markedly excentric as in *Amphoracrinus*, but is situated in a central or sub-central position on summit of tegmen ; ornamentation finely granular or vermiculate.

Genotype.—Amphoracrinus clitheroensis Wright, *Geol. Mag.*, lxxix, 1942, 272 ; pl. x, figs. 1–4.

Pimlicocrinus clitheroensis (Wright)

Pl. III, figs. 12, 13, 18, 19, 20.

Theca of moderate size ; dorsal cup very shallow, basal area forming a low flattened cone, not always visible in side view ; lower brachials up to IIIBr$_1$ incorporated in cup and nearly in line with basal area of cup ; iBr areas narrow and depressed ; column facet in shallow cavity, axial canal pentangular ; IIBr$_1$ axillary ; tegmen high, more sloping on anterior side, composed of numerous, rather small, irregularly shaped plates ; orals slightly larger than others but not conspicuously so ; tegminal plates above fixed brachials sometimes spiniferous ; iBr few, usually limited to a double row of narrow plates after the first iBr ; brachial lobes only slightly produced beyond line of tegmen ; anal tube nearly central ; ornamentation finely vermiculate or granular.

Holotype.—J. W. Coll. No. 2382 (Pl. III, figs. 18–20).

Paratypes.—No. 2393 (Pl. III, figs. 12, 13), No. 2394.

Locality.—Coplow Knoll, Clitheroe.

Dimensions of Holotype.—Height of calyx over all, 28·4 mm. ; height of dorsal cup, less than 2 mm. ; greatest width across calyx at IIIBr$_1$, anterior to posterior, 29·9 mm. ; left anterior to right anterior, 29 mm. ; width of tegmen at top near anal opening, 6 mm.

Dimensions of Paratype, No. 2393.—Height over all, 19 mm. ; height of dorsal cup, 1·5 mm. ; greatest width across calyx at IIIBr$_1$, anterior to posterior, 20·4 mm. ; left anterior to right anterior, 20 mm. ; width of tegmen at top of broken part, 9·4 mm.

Dimensions of Smallest Paratype, No. 2394.—Height over all, 15 mm. ; height of dorsal cup, 1 mm. ; greatest width across calyx, left anterior to right anterior, 18 mm. ; anterior to posterior, 18 mm. ; width at top, 5·5 mm.

Remarks.—The chief characters in the calyx of *Amphoracrinus* have already been noted. In *Pimlicocrinus* the dorsal cup, compared with Clitheroe species of *Amphoracrinus*, is much shallower, sometimes invisible from the side, the IIBr$_1$ are axillary, and the brachials up to IIIBr$_1$ are included in the cup. In some American species of *Amphoracrinus*, e.g. *Amphoracrinus spinobrachiatus* (Hall) and *A. divergens* (Hall), features like these as well as the low nature of the cup seem to be characteristic (Wachsmuth and Springer, 1897, pl. lxii, figs. 1–10), so that by themselves such characters are not distinctive of *Pimlicocrinus*. The chief difference, however, between *Amphoracrinus* and *Pimlicocrinus* is in the position of the anal tube. In the former genus it is excentric, in the latter central or sub-central. In addition, the oral plates in *Amphoracrinus* are large and conspicuous, in *Pimlicocrinus* the orals are not specially differentiated from adjoining plates. Although the orals can be recognized quite distinctly in *Pimlicocrinus* they do not occupy a flat specialized area at the summit of the tegmen as in *Amphoracrinus*, but merge with the other plates of tegmen where it becomes constricted for the extension of the anal tube. In the central or sub-central position of the anal tube *Pimlicocrinus* holds to *Amphoracrinus* a somewhat similar position as that of *Alloprosallocrinus* to *Agricocrinus* (Wachsmuth and Springer, 1897, pl. xliii, figs. 1–14). In the holotype of *Pimlicocrinus clitheroensis* the cup is very low. When the specimen is viewed from the anterior side the cup itself is invisible owing to the overhang of the brachial lobes. On the posterior side, however, the overhang is not so great and the cup can be readily seen from this position. The plates of the tegmen are rather irregular in shape and small and numerous, those above the fixed brachials tending to be spiniferous as in *Amphoracrinus*. The tegmen is fairly symmetrical although in the holotype the slope on the anterior side is less steep than on the posterior. In the holotype part of the anal tube is broken away near the point of greatest constriction of the tegmen. In the paratype No. 2393 (Pl. III, fig. 13) the tegmen is also broken at the top, rather lower down than in the holotype, but the general features of this specimen are the same except perhaps that the tegminal plates as a whole are more " knobby " in character. This also applies to the other small paratype No. 2394, which is nearly complete and shows well the anal opening at the summit in a central position. The cup in both paratypes is of the same general character as in the holotype (compare Pl. III, figs. 12 and 19). Owing, however, to the smaller degree of overhang of the brachial lobes in these specimens the cup itself up to the radial circlet is distinctly visible from all sides. The general aspect of the theca in the present species is not unlike that of *Amphoracrinus spinobrachiatus* (Hall) already mentioned, except that in our species there are no spines on the orals and the anal tube is central not excentric as in the American form.

Pimlicocrinus latus sp. nov.

Pl. III, figs. 1–11, 14–17, 21, 22.

Theca of moderate size ; dorsal cup low but rather higher than in previous species and usually visible from the side ; area of basals and radials somewhat wide ; iBr few, but iBr areas wider than in previous species ; lower brachials up to IIIBr_2 may be incorporated in cup ; brachial lobes greatly extended beyond tegmen with iBr areas far back between lobes ; tegmen moderate in height composed of comparatively few rather large, thick, and bluntly pointed or spiniferous plates ; in posterior IR they are smaller and more numerous ; orals not specially differentiated ; anal opening at end of a tube occupying a sub-central position on summit of tegmen ; plates usually smooth, with traces of rather coarse granular ornamentation.

Holotype.—J. W. Coll. No. 2391 (Pl. III, figs. 1–4).

Paratype.—J. W. Coll. No. 2386 (Pl. III, figs. 11, 14, 21, 22) ; No. 2387 (Pl. III, figs. 7, 8) ; No. 2388 (Pl. III, figs. 9, 10, 15) ; No. 2389 (Plate III, figs. 6, 16, 17) ; No. 2390 (Pl. III, fig. 5).

Locality.—Coplow Knoll, Clitheroe.

Dimensions of Holotype.—Height over all, 23·7 mm.; width across calyx from extremities of left and right lateral lobes at IIIBr, estimated, 39·8 mm.; average width of calyx between lobes, 24 mm.

Dimensions of Paratype No. 2389.—Height of cup, about 3 mm.; height of calyx over all, 19·6 mm.; width across calyx from extremities of left and right lateral lobes, estimated, 29 mm.; width between lobes, 19·7 mm.; width of tegmen at constriction of anal tube, 3·9 mm.

Remarks.—The material upon which this species is based consists of seven specimens of various sizes, representing different stages in growth. The species differs from the preceding in its relatively lower tegmen, relatively larger tegminal plates, and particularly in the greater extension of the brachial lobes. The holotype is the largest specimen and is fairly well preserved except that part of the cup is damaged owing to difficulty of extraction from a hard limestone matrix. The extension of the right lateral brachial lobe is complete, the anterior one nearly so, but the others are broken near their junction with tegmen (Pl. III, fig. 1–4). The tegmen is gently rounded but is more straight on the posterior side, a feature common to all the specimens. In the holotype the lobe extensions include the brachials of the dorsal cup up to IIIBr_2, after which the arms are free. Like the holotype all the other specimens are more or less incomplete, none of them showing the full extension of the brachial lobes all round the calyx. Generally these extensions are broken off at varying distances from the calyx. In one or two specimens, however, where a lobe is complete there are indications to show that in the younger forms the arms were free from IIBr_1 or IIIBr_1 (Pl. III, figs. 9 and 10). Most of the specimens show little trace of ornamentation, but there is evidence here and there that it was somewhat coarsely granular. The tegminal plates are large and thick, heavy in appearance, and of a bluntly pointed or spiniferous character.

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EXPLANATION OF PLATES

All figures natural size and all specimens in author's collection except two specimens shown on Plate IV, figs. 12, 13, and 14, which belong to the collection of Mr. Stanley Westhead, of Clitheroe.

Plate III

Figs. 1–3.—*Pimlicocrinus latus* sp. nov., right lateral, posterior and summit views of the holotype, No. 2391.
Fig. 4.—*Pimlicocrinus latus* sp. nov., part of basal view of holotype, No. 2391.
Fig. 5.—*Pimlicocrinus latus* sp. nov., posterior view of small paratype, No. 2390.
Figs. 6, 16, 17.—*Pimlicocrinus latus* sp. nov., anterior, summit, and basal views of paratype, No. 2389.
Figs. 7 and 8.—*Pimlicocrinus latus* sp. nov., posterior and summit views of paratype, No. 2387.
Figs. 9, 10, and 15.—*Pimlicocrinus latus* sp. nov., basal, summit, and posterior views of paratype, No. 2388.
Figs. 11, 14, 21, and 22.—*Pimlicocrinus latus* sp. nov., summit, left and right lateral, and posterior views of paratype, No. 2386.
Figs. 12 and 13.—*Pimlicocrinus clitheroensis* (Wright), basal and posterior views of paratype, No. 2393.
Figs. 18, 19, and 20.—*Pimlicocrinus clitheroensis* (Wright), posterior, basal, and summit views of holotype, No. 2382.

All specimens on this Plate from Coplow.

Plate IV

Figs. 1 and 5.—*Amphoracrinus gilbertsoni* Form II, anterior and posterior views of a specimen from Coplow, No. 2425.
Figs. 2, 3, 4, and 9.—*Amphoracrinus gilbertsoni* Form I, from Bellman. Posterior, basal, summit, and anterior views of No. 2406.
Figs. 6 and 7.—*Amphoracrinus atlas* McCoy, a small specimen referred to this species from Bellman, posterior and summit views, No. 2408.
Fig. 8.—*Amphoracrinus gilbertsoni* Form I, from Coplow, right lateral view showing anal tube partly preserved, No. 2420.
Fig. 10.—*Amphoracrinus gilbertsoni* Form I, left lateral view of a specimen from Bellman, No. 2407.
Fig. 11.—*Amphoracrinus gilbertsoni* Form III, posterior view of a specimen from Bellman, No. 2411.
Fig. 12.—*Amphoracrinus gilbertsoni* Form I, left lateral view of a small specimen from Coplow, Stanley Westhead Coll.
Figs. 13 and 14.—*Amphoracrinus gilbertsoni* Form I, left lateral and posterior views of a small specimen from Coplow, Stanley Westhead Coll.

Plate V

Figs. 1, 3, and 4.—*Amphoracrinus gilbertsoni* Form I, anterior, summit, and basal views of a specimen from Knoll Wood, No. 2432.

Fig. 2.—*Amphoracrinus gilbertsoni* Form I, from Knoll Wood, posterior view of No. 2431.

Figs. 5, 8, and 12.—*Amphoracrinus gilbertsoni* Form I, three specimens from Coplow, showing the posterior area with anal X surmounted by three plates instead of the usual two. Nos. 2423, 2430, and 2422.

Fig. 7.—*Amphoracrinus gilbertsoni* Form I, from Knoll Wood, anal X is also surmounted by three plates, No. 2433.

Fig. 6.—*Amphoracrinus gilbertsoni* Form I, the largest specimen from Coplow in which tegmen and cup are about equal in height, No. 2420.

Figs. 9 and 13.—*Amphoracrinus gilbertsoni* Form I, two small specimens from Coplow; Fig. 9, left lateral view; Fig. 13, anterior view. Nos. 2427 and 2434.

Fig. 10.—*Amphoracrinus gilbertsoni* Form II, left lateral view of a large specimen from Coplow, No. 2424.

Fig. 11.—*Amphoracrinus compressus* sp. nov. posterior view of the holotype from Knoll Wood, No. 2418.

PLATE VI

Figs. 1–3.—*Amphoracrinus turgidus* sp. nov. from Bellman, posterior, anterior, and summit views of paratype, No. 2413.

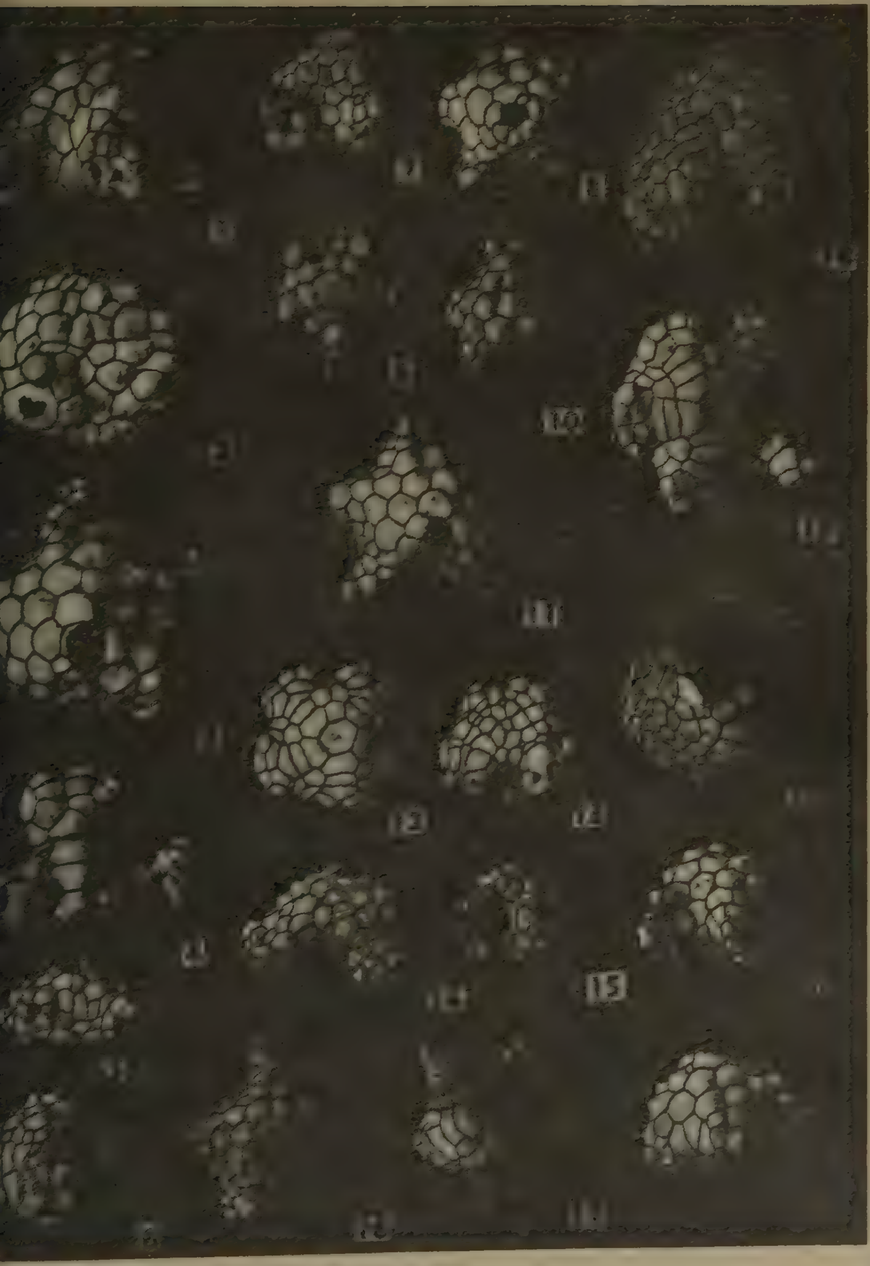
Figs. 5–7.—*Amphoracrinus turgidus* sp. nov. from Bellman, anterior, posterior, and summit views of the holotype, No. 2412.

Figs. 4 and 12.—*Amphoracrinus gilbertsoni* Form III, from Coplow, anterior and posterior views of No. 2426.

Figs. 8–10.—*Amphoracrinus gilbertsoni* Form III, from Bellman, left lateral, posterior, and summit views, No. 2409.

Fig. 11.—*Amphoracrinus gilbertsoni* Form III, from Bellman, posterior view of No. 2410.

Figs. 13–15.—*Amphoracrinus gilbertsoni* Form I, from Coplow, left lateral, posterior, and summit views of a small specimen, No. 2429.



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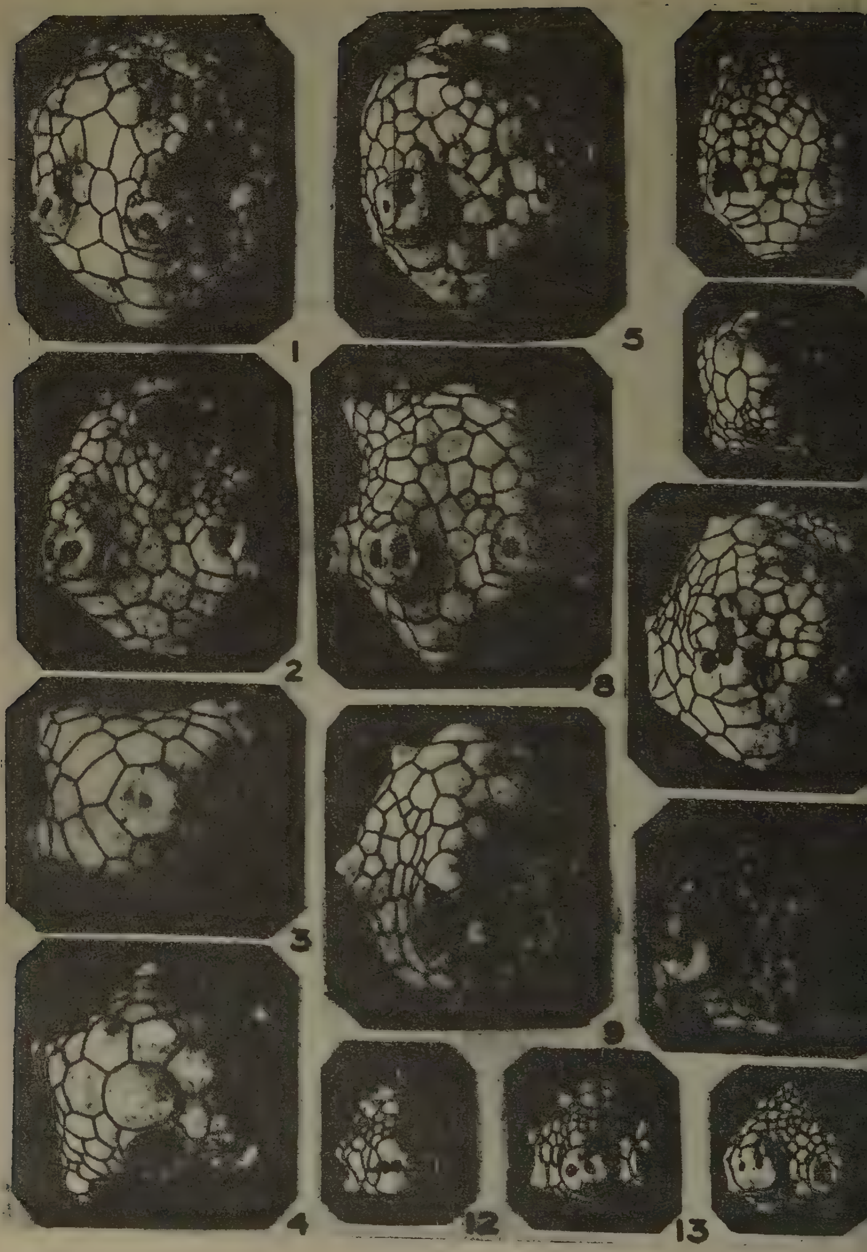
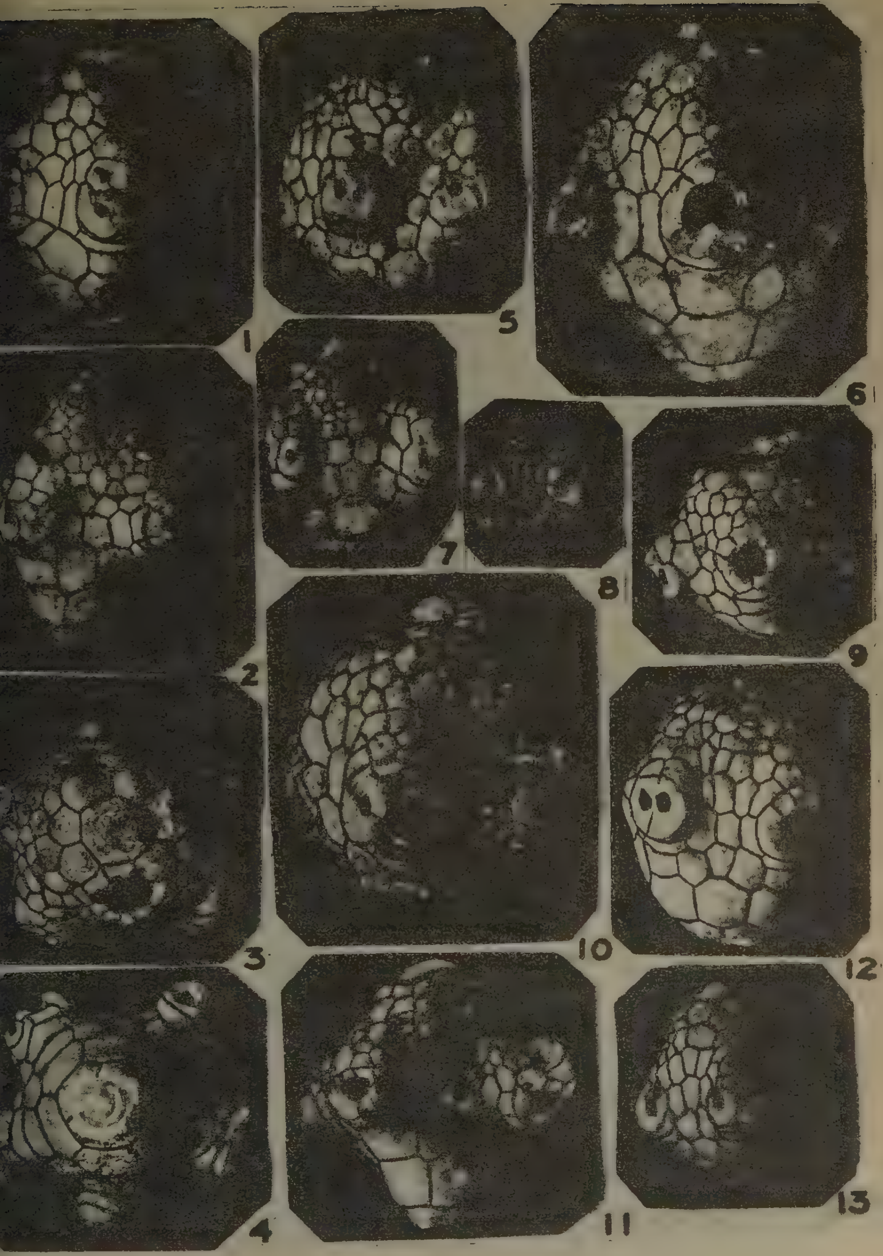


J. Wright Photo.

AMPHORACRINUS.



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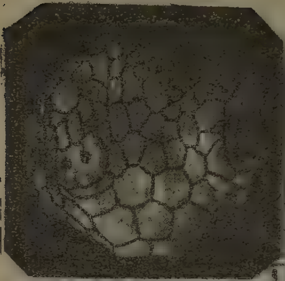

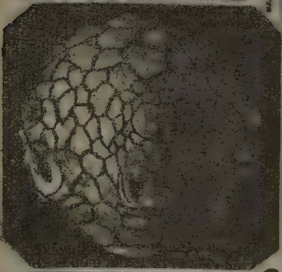

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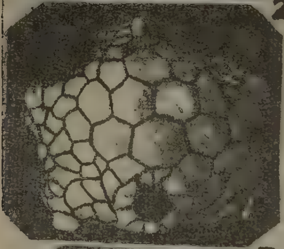

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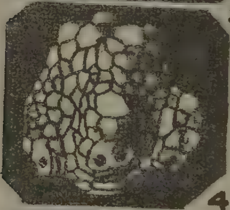

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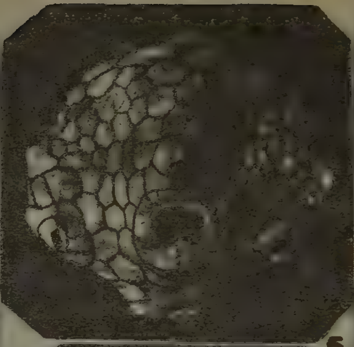

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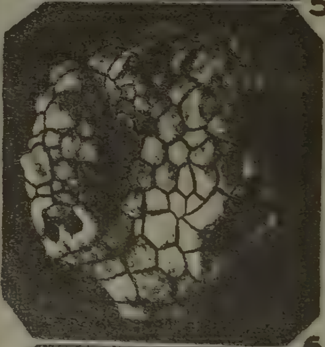

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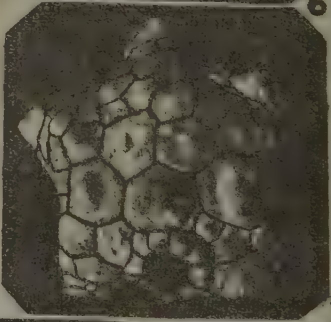

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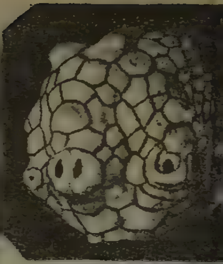

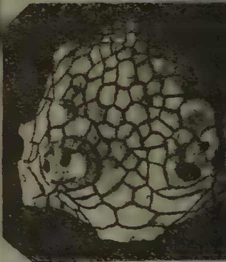

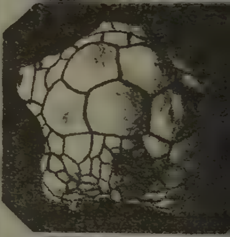

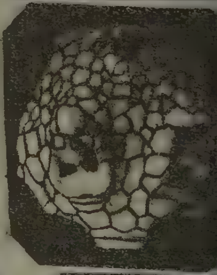

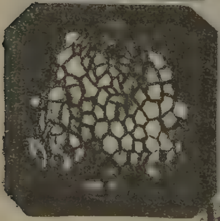

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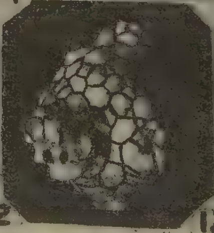

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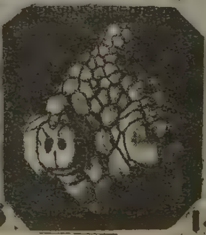

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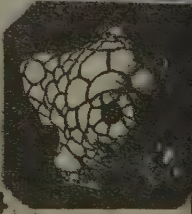


J. Wright Photo.

AMPHORACRINUS.

Notes on Certain Upper Devonian Brachiopods figured by Whidborne

By F. R. C. Reed

(*Continued from p. 78*)

Genus : Productus J. Sowerby

Subgenus : Dictyoclostus Muir-Wood

Productus (*Dictyoclostus* ?) *porteri* sp. nov.

Whidborne gave a composite description of certain specimens from the Upper Devonian of Pilton and other localities which he grouped together and ascribed to the Carboniferous species *P.* (*Buxtonia*) *scabriculus* Mart. (Whidborne, 1897, 170, pl. xx, figs. 16–18, pl. xxi, fig. 12), but he considered that it was difficult to distinguish some of them from those which he ascribed to *Strophalosia productoides.* We cannot agree with his reference of any of them to Martin's Carboniferous species. The best preserved and first example [H. 286] which he figured (1897, pl. xx, fig. 16) is a pedicle-valve from " Smoking House Lane ". It has a transversely subquadrate shape with subrectangular cardinal angles not produced ; the body is strongly arched longitudinally but only moderately convex transversely, and it has a weak median longitudinal depression, but descends steeply on each side to the small ears ; it is covered by regular continuous rounded costae of equal size, about fifty in number, some of which bifurcate at about one-third to two-thirds their length, and very few of them show any small swellings on their course as in *P. scabriculus* ; a few faint narrow concentric rugae are traceable on the posterior third of the body producing weak coarse reticulation ; the umbo is very broad, rounded and incurved, projecting over the hinge-line ; the ears, which are much depressed but not sharply marked off from the body, are triangular in shape and are crossed by a few narrow concentric rugae which bifurcate somewhat irregularly before reaching the hinge-line ; a few large coarse spinose tubercles or spine-bases lie near the junction of the body with the ears. This pedicle-valve is sufficiently preserved to indicate a distinct species, for which the name *porteri* is proposed.

The second specimen [H. 240] of an imperfect pedicle-valve which Whidborne figured (pl. xx, fig. 17) apparently belongs to the same species as the one above described ; but the nearly perfect brachial valve [H. 241] from Pilton, of which Whidborne figured (pl. xx, fig. 18) only a very small portion of the surface, may be separable, for the ribbing is rather coarser and the ribs are nodulated where crossed by strong concentric regular narrow wrinkles. Paeckelmann (1931, pp. 197, 203), denied the identity of any of these specimens with the typical *P.* (*Buxtonia*) *scabriculus*, and expressed the opinion (1931, p. 67, t. 3, figs. 6–11) that they might be identical with his *P. caperata* var. *radiata*, but apparently he had not seen Whidborne's figured specimens and we cannot agree with this view. Dehée (1929, p. 38, pl. vi, figs. 7–12) figured shells from Etroeungt as *P.* (*B.*) *scabriculus*, but they do not appear to belong to the same species as those from Pilton, being subhemispherical, and less transverse in shape and without a median depression. Peetz (1901, p. 372, t. v, figs. 8*a–c*) expressed the opinion that his species from Kuznetzk named *Productus meisteri* much resembled Whidborne's *P. scabriculus.* Wulff's *P.* aff. *scabriculus* from the Fammenian of the Aachen area (1923, p. 47, t. 2, fig. 3) is neither like Martin's nor Whidborne's species judging from the figure and description. The Turkish species *Productella ptychodes* Paeckelmann (1925, p. 123, t. 5, figs. 12*a–d*) appears to bear a closer resemblance. The American species from the Mississippian named *P.* (*B.*) *incurvatus* Sutton and Wagner (1931, p. 126, pl. 5, figs. 18, 19; Sutton, 1938, p. 564, pl. 65, fig. 5) may also perhaps be compared.

As above mentioned, Whidborne's other specimen [H. 279] (pl. xxi, fig. 12) from Pilton may be best referred to *P. caperata* var. *radiata* Paeck., and is quite distinct from his other examples of so-called *P. scabriculus* figured on pl. xx, figs. 16–18 which Paeckelmann (1931, p. 67) put in that variety. It may be suggested that Whidborne's specimens (other than the one figured on pl. xxi, fig. 12, and above described) belong to the subgenus *Dictyoclostus* Muir Wood (1930, p. 103), and not to *Buxtonia* Thomas, as emended by Miss Muir Wood (1930, p. 107), of which Sutton (1938, p. 564) considers that the chief distinguishing features are the character of the costae and associated spines, whereas in our Pilton form it is the division of the costae and the bifurcation of the concentric rugae, and the obsolescence or absence of spine-bases on the costae which mark it. We may name it *porteri*, as the type specimen figured by Whidborne, pl. xx, fig. 16, was in the Porter collection presented to him.

Subgenus: STRIATIFERA Chao

Productus (*Striatifera*) *corrugatus* McCoy, var. nov. *spinulifera*

Whidborne's specimens (1897, p. 173, pl. xxi, figs. 4, 5) which he figured from Fremington, consist of a pedicle-valve (ventral) [H. 454] (fig. 4) and a brachial valve (fig. 5) [H. 455] belonging to a smaller individual. He referred both to *Productus corrugatus* McCoy (1844, p. 107, pl. xx, fig. 13) which Davidson (1861, p. 148) put as a synonym of *P. cora* D'Orb., but we must agree with Whidborne that they must be separated from the typical *P. cora* and can hardly be placed in any of its established varieties. McCoy did not mention the minute spinules on the lirae and Whidborne's figures do not show them, while his description is hardly sufficiently detailed, so that the following remarks may be added. The so-called " ventral " valve [H. 454] (fig. 4) is subglobose, rounded and strongly swollen, but only the left half is preserved; it has a prominent incurved umbo overhanging the hinge-line which is hidden in matrix; there are no ears as he stated, though he said they were " small and undefined ". There are 2–3 rather strong short rounded concentric folds on the posterior lateral slopes of the valve. The ornamentation consists of alternately large and small uniform regular equidistant linear radial lirae; these are not flexuous, but the lateral ones curve back on each side to the hinge-line; all the lirae bear along their length minute sharp granules or spinules which are less closely placed on the lateral lirae where they are well preserved, but elsewhere the surface is more or less worn, so that the lirae appear in places to be smooth. The lirae large and small together number about 12–14 in every 5 mm. on the margin. The example [H. 455] of the so-called " dorsal " valve (fig. 5) consists of the impression of a nearly flat subcircular valve becoming gently concave in he posterior median region ; it is crossed by three complete concentric subangular folds ; the hinge line is straight and equal to or rather less than the width of the valve ; there is a narrow hinge-area and a broad-based short bilobed cardinal process with each lobe grooved on its face and notched at its tip.

Dimensions.	[H. 454] FIG. 4	[H. 455] FIG. 5
Length . .	*c.* 36 mm.	19 mm.
Width (estim.) .	45 mm.	*c.* 20 mm.
Convexity . .	*c.* 13 mm.	

Remarks.—The spinous character of the lirae and their regular alternation in size are distinguishing features from *P. cora*, and the former character is not mentioned or shown in the figures of *P. corrugatus* by McCoy, so that we may give it a distinctive name for which we suggest *spinulifera*. None of the lirae in these specimens are flexuous or divide, though Whidborne stated that this was sometimes the case. We may probably place it in the subgenus *Striatifera* on account of its general characters, though the minute spinuliferous character of the lirae is peculiar. The species has been recorded from D 2 beds in Gower and described by Délepine (1928, p. 26, pl. iv, figs. 45, 46 ; pl. vi, figs. 67–69) from the Tournaisian of Dinant. Paeckelmann also (1931, p. 210, t. xix, figs. 1, 2) has described it, and considered *P. rhenanus* Paeck. (1931, p. 225, t. xx, figs. 5–7) and *P. ovatus* Hall (1858, p. 674, pl. 24, fig. 1 ; Weller, 1914, p. 132, pl. xvi, figs. 1–15 ; Sutton, 1938, p. 558, pl. 65, figs. 8–13) from the Mississippian to be allied species.

Subgenus : MESOPLICA nov.

Shell subquadrate, rounded. Pedicle-valve strongly convex, with a weak narrow median sinus or sulcus for its whole or part of its length holding a narrow rounded fold which bears a few strong nodes or spines ; lateral lobes with more or less distinct somewhat irregular low rounded ribs without ? spines ; umbo broad, obtuse, incurved ; ears small, bearing a few spines. Brachial valve strongly geniculated ; disc flat, large, bearing more or less pustulated radial ribs on each side of a narrow median sinus ; geniculated portion of valve bearing only a few low thick narrow folds ; ears flattened, depressed, concentrically wrinkled, Genotype : *Leptaena praelonga* J. de C. Sowerby.

Remarks.—The distinguishing features of this subgenus are the median fold in the sinus of the pedicle-valve with the costation of the lateral lobes, the non-geniculation of this valve, and the absence of concentric rugae on its surface. Dehée (1929, p. 41) and Paeckelmann (1931, p. 105, t. 5, figs. 8–13) refer the species to the subgenus *Avonia* Thomas, of which the type is *P. youngianus* Dav., but if we follow Miss Muir Wood's revised definition of that subgenus (1928, p. 36 ; 1930, p. 106) and Sutton's later limitation (1938, p. 565) we can hardly leave it there. We may note that a similar peculiar median fold in the pedicle-valve is found in the Carboniferous species *P. mesolobus* Phillips, as noticed by McCoy (1854, p. 390), Davidson (1861, p. 102) and Drevermann (1902, p. 516); but Chao (1927, p. 25; 1928, p. 61), Miss Muir Wood (1930, p. 107), and Paeckelmann (1931, p. 118) (who considers the development of this feature merely a case of convergence), place that species in the genus or subgenus *Plicatifera*, of which the type is *P. plicatilis* J. de C. Sowerby, a species which in other respects has completely different characters to *P. praelongus*. We may note also that in *P.* (*Linoproductus* ?) *nodosus* Newberry (Dunbar and Condra, 1932, p. 246, pl. 32, fig. 6) from the Pennsylvanian a similar median fold armed with large spines is developed, and Kindle (1909, p. 18, pl. iv, figs. 9–12) has described a species from New Mexico as *Productella coloradoensis* var. *plicata* which much resembles *P. mesolobus*. But we may doubt with Paeckelmann (1931, p. 105) if the specimen from Sett'e ascribed by Davidson (1861, pl. xxxi, fig. 6) and by Thomas (1914, pl. xx, figs. 19–21) to *P. mesolobus* belongs to that species, and is not a degenerate descendant of *P. praelongus*, thus attributable rather to the subgenus *Mesoplica*.

Productus (*Mesoplica*) *praelongus* (J. de C. Sowerby)

In the British examples of this species only internal casts of the pedicle-valve appear to be known, such as Whidborne's specimens represent, but Dehée (1929, p. 41, pl. vi, figs. 13–16) has figured more perfect specimens from Etroeungt as belonging to this species showing the shell and the costae bearing occasional small spines, such as are only seen in a few internal casts from the Pilton beds which also seem to have more irregularly sinuous and ramifying fine striae on the interior of the shell. The peculiar strong rounded narrow fold bearing a few large hollow spines along it and situated in the middle of the median sinus on the pedicle-valve [H. 271] seems to be clearly developed only in certain of the specimens attributed to it, but it can be distinguished in Sowerby's type (1840, pl. 53, fig. 29); it is usually chiefly developed in the anterior part of the valve, and is more pronounced in certain examples such as Davidson (1866, p. 102, pl. xix, figs. 22–25) and Whidborne (1897, p. 168, pl. xx, figs. 12, 12*a*, 13, 13*a* [H. 271]) figured. That the costae die out near the margin and are there replaced by a few narrow widely placed folds is not mentioned in their description of the species. Whidborne (1897, pl. xx, fig. 12) figured the disc of a brachial valve which shows the strong geniculation of the valve and coarse pustulated costae over the disc, but the specimen has only the fewer and thicker costae or narrow radial folds on the geniculated portion which is not shown in his figure.

Nalivkin (1930, p. 40, t. ii, figs. 3, 4) compared *P. vlangali* Roman. from Turkestan with *P. praelongus*, and Wulff (1923, p. 47) described a shell allied to it from the Fammenian of Aachen which seems to possess the typical characters. We may also compare the Mississippian species from Iowa named *P. mesicostalis* Weller (1914, p. 114, pl. xi, figs. 12–16) and especially *P. schindewolfi* Paeckelmann (1931, p. 104, t. 5, fig. 5) which he remarks is much like *P. praelongus*.

Subgenus : PRODUCTINA Sutton

Productus (*Productina* ?) *simplicior* Whidborne

The specimens [H. 277–8] which Whidborne figured from Poleshill (1897, p. 169, pl. xx, figs. 14, 15) as *Productus praelongus* (Sow.) ? var. *simplicior* differ considerably from the type of that species and should be considered to be of specific rank. They lack the median sinus and its fold on the pedicle-valve and are of a different shape, being elongated and very convex transversely and longitudinally, and they have a short hinge-line and broader umbo, so that they are much more like *P.* (*Avonia*) *niger* Gosselet as figured and described by Dehée (1929, p. 39, pl. vi, figs. 1–6) and by Paeckelmann (1931, p. 98, t. 4, figs. 24, 25, t. 5, figs. 1, 2) from the Etroeungt stage, though Paeckelmann (1931, p. 104, t. 5, figs. 6*a*–*d*) still keeps *P. simplicior* as a variety of *P. praelongus* as did also Nalivkin (1930, p. 40, t. ii, fig. 8). The impression of the exterior of a pedicle-valve from Barnstaple in the Sedgwick Mus. [H 1266 *a*, *b*] shows the regular ribbing of the elongated convex pedicle-valve with the costae bearing widely and irregularly spaced small spine-bases as in *Productella arcuata* (Hall) (1858, p. 518, pl. 7, figs. 4*a*, *b*) from the Kinderhook of Iowa, and it also appears somewhat to resemble *Productella costatula* Hall (1867, p. 180, pl. xxvi, figs. 9–15 ; Hall and Clarke, 1893, pl. xvii, figs. 18–20, 35) from the Chemung formation. But probably Sutton's new genus or subgenus *Productina* (1938, p. 551) should be the correct place for Whidborne's *P. simplicior* rather than *Avonia*, though *P.* (*Avonia*) *muricatus* Phillips, as figured by Davidson from the British Lower Carboniferous (1861, p. 153, pl. xxxii, figs. 10, 11) bears a considerable resemblance. Paul (1937, p. 435) would put the apparently related species *P. niger* in the subgenus *Buxtonia*, but his reasons for so doing have not yet been published. *P. fallax* Pander as described by Frech from Persia (1900, p. 194, t. xv, fig. 19) seems to be allied to *P. simplicior*. Vaughan (1905, p. 287, pl. xxv, figs. 1, 1*a*) compared his new species *Productus bassus* with *Productella costatula* Hall and curiously also with *P. hystricula*, but *P. bassus* bears very slight resemblance to *P. simplicior* and seems more like Whidborne's *P.* cf. *scabriculus*, while *P. hystricula* is completely different and was put by Hall and Clarke (1892, pl. xviii, fig. 30) in *Strophalosia*.

Subgenus : PRODUCTELLINA nov.

Productus (*Productellina*) *fremingtonensis* sp. nov.

Pedicle-valve small, subglobose, almost hemispherical ; hinge-line nearly equal to width of valve ; cardinal angles subrectangular ; ears small, depressed, undifferentiated from body, bearing narrow concentric rugae ; umbo broad, incurved, slightly overhanging hinge-line, having small apical pit or cicatrix. Surface of valve covered with closely placed somewhat irregular undulating coarse imbricating sublamellose concentric rugae, some of which, especially in the umbonal and posterior region, bear a few small low round tubercles irregularly scattered, with traces of some delicate recumbent spinules. A hinge-area and bases of cardinal spines are doubtfully present. Inner layer of shell covered with fine radial striae.

Dimensions.

Length	13·0 mm.
Width	11·0 mm.
Height	4·5 mm.

Remarks.—The above described small specimen [H. 287] from Fremington was not correctly figured by Whidborne (1897, p. 172; 1898, pl. xxii, fig. 2) who curiously regarded it as "probably the dorsal valve of *P. interruptus* Sow." (1840, pl. 56, fig. 7) but it certainly is not referable to that species, and it is completely different from the first specimen [H. 288] from Pilton, which he assigned to that species (pl. xxii, fig. 1) for that has strong radial costae; the portions of a much crushed and imperfect third specimen (pl. xxii, fig. 3) which he also figured from Pilton possesses weak radial costae and cannot be considered as identical, but is too poorly preserved for a satisfactory determination. The Fremington specimen consists of a pedicle-valve which is apparently comparable with *Productella hallana* Walcott (1884, p. 130, pl. xiii, figs. 17, 17*a*) of the Upper Devonian of the United States, and also recorded by Toll and Tschernyschew from Russia. The generic reference of that species is uncertain, but Schuchert (1897, p. 315) retained it in the genus *Productella*, though it differs much from the genotype and must be regarded as belonging to another genus. Thus Schuchert subsequently (1913, p. 568, pl. li, figs. 21–23) put it in the Productid subgenus *Marginifera*. We may draw attention to its resemblance in certain respects to *P. sericeus* von Buch which Tschernyschew (1887, p. 110, t. xiv, fig. 28) figured from the Urals. Amongst American species *Productella coloradoensis* Kindle (1909, p. 17, pl. iv, figs. 2–6) and *P. spinigera* Kindle (1909, p. 19, pl. v, figs. 1–4) from the Ouray Limestone may be allied, but the Turkestan example of the latter represented by Nalivkin's figure (1930, p. 37, t. ii, fig. 12) seems to be different. *Productus* ? *indianensis* Hall, of the Mississippian of Indiana, which Weller (1914, p. 131, pl. xviii, figs. 7–10; pl. lxxxiii, figs. 12, 13) thought might belong to the genus *Productella*, seems to bear a greater resemblance to the Fremington shell, and one of Girty's figures of examples of *P. cooperensis* (Swallow) from the Madison Limestone of the Yellowstone Park (Girty, 1899, p. 528, pl. lxviii, fig. 9, non 8), a species which Weller (1914, p. 98) includes in *Productella concentrica* Hall, seems to be comparable. The species from the Hackberry Stage of the Upper Devonian of Michigan named *Productella walcotti* Fenton (1924, p. 119, pl. xxvi, figs. 1–7) is probably closely allied to our Fremington shell. Sutton (1938, p. 565) puts *P. indianensis* Hall, with a query in the genus *Avonia* Thomas, together with *P. cooperensis* rather than in *Productella*. But he recognizes that such small non-costate forms including *P. indianensis* represent a special group, and to this subgenus (for which the name *Productellina* is proposed) we must assign Whidborne's figured specimen above defined. There is another unfigured example [H 1665] in the Whidborne Collection from the same locality as the type, but not so well preserved.

Genus : Chonetes Fischer de Waldheim

Subgenus : Plicochonetes Paeckelmann

Chonetes (*Plicochonetes*) *plebeia* Schnur, var. nov. *sauntonensis*

As Whidborne remarked in connection with the specimen [H. 293] which he described and figured from Saunton (1898, p. 177, pl. xxii, fig. 4) as *C. hardrensis* Phillips, this species is primarily Carboniferous, and he was very doubtful if the Devonian shells should be included in it, though he considered that there was great variability in its characters. From an examination of his figured specimen there seems to be sufficient reason for separating it. Leidhold (1928, p. 20) considered that *C. sarcinulata* (Schloth.) was identical with Phillips's *C. hardrensis*, and he included in it all the Devonian shells which Davidson (1866, p. 94, pl. xix, figs. 6–9) had referred to the last-mentioned Carboniferous species, but we cannot agree with this conclusion. McCoy (1852, p. 24) limited the name *hardrensis* to the Carboniferous form with reason.

We may better refer Whidborne's specimen to a variety of *C. plebeia* Schnur (1853, p. 226, 244, t. xlii, fig. 6*a*) as interpreted by Oehlert (1883, p. 517, pl. xiv, fig. 3) and by Tschernyschew (1887, p. 110, t. xiv, figs. 22–24) from the Upper Devonian of the Urals, and we may compare it also with *C. nana* de Verneuil (1845, p. 245, t. xv, fig. 12) which the present author has recorded from the Pamirs (1922, p. 93, pl. xiv, fig. 10).

Whidborne's description is not quite sufficient, as he omitted to state that there are 45–50 costellae round the margin, most of which have increased to that number by bifurcation at various distances from the umbo, and it must be pointed out that the specimen is subquadrate in shape and not suboval as he stated. It measures 5·25 mm. in length and 7 mm. in width.

It is noticeable that the species from the Devonian of Szechuan which Loczy named *C. orientalis* (1898, p. 28, t. vii, figs. 12–17 ; Grabau, 1931, p. 22) and especially its variety *admixta* Reed (1927, p. 12, pl. ii, figs. 2–4 ; Grabau, 1931, p. 24, pl. i, figs. 3, 4) from Yunnan, much resemble this British form. *C. coronata* Conrad (Hall, 1867, p. 133, pl. 21, figs. 9–12 ; Kindle, 1900, p. 502, pl. iv, fig. 7) may be regarded also as allied. Maillieux (1932, p. 33, pl. ii, figs, 1, 1*a*, 2, 2*a*) who gives a very full synonomy of *C. sarcinulata* does not include *C. hardrensis* in it, and practically all his references are to Lower Devonian occurrences of the species. The difficulty of deciding what are the typical characters of the original of *C. hardrensis* was pointed out by Stanley Smith (1925, p. 86) in connection with specimens of *Chonetes* from the Lower Carboniferous of the Bristol area.

Chonetes cf. *syrtalis* (Conrad)

The second specimen [H. 296] attributed by Whidborne with a query (1898, p. 179, pl. xxii, fig. 8) to *C. illinoisensis* Worthen, and doubtfully found at Fremington, consists of the internal cast of a gently convex pedicle-valve which is nearly as long as wide, has acutely pointed (but not produced) cardinal angles, and possesses 2–3 long widely spaced cardinal spines at right angles to the hinge-line, the outermost one being the longest; a short median septum is also present. The marginal parts of the valve show a few widely separated small pustules on the interior, but the rest of its surface is so much abraded that only traces of fine radial lines and punctae are here and there visible.

This specimen can hardly be referred to the same species as the first figured one which Whidborne placed in Worthen's species; its true location is difficult to decide as it is not well preserved. It may be best compared with *C. syrtalis* (Conrad) as figured by Hall (1867, p. 133, pl. xxi, figs. 13*a–d*), a species which is now generally included in *C. coronata* Hall (1867, p. 133, pl. xxi, figs. 9–12). The first specimen [H. 295] figured by Whidborne (pl. xxii, fig. 7) is quite unlike it and does not resemble *C. illinoisensis* as re-defined and figured by Weller (1909, p. 297, pl. 12, fig. 11; 1914, p. 84, pl. viii, figs. 63–70) from the Lower Carboniferous of the United States, but its affinities are obscure. If the appearance of a minutely crenulated hinge-line is a real character we should have to transfer it to the genus *Leptostrophia*, but this is very doubtful.

Genus: SPIRIFER Sowerby

Subgenus: GURICHELLA Paeckelmann

Spirifer (*Gurichella*) *bouchardi* Murchison, var. *belliloci* Rigaux

One [H. 263] of the specimens described and figured by Whidborne (1897, pl. xix, fig. 10) from Poleshill as belonging to *Spiriferina cristata* (Schloth.) var. *octoplicata* J. de C. Sowerby, is the impression of a pedicle-valve, but it cannot be referred to that genus or species. It belongs to *Spirifer bouchardi* Murchison (1840, p. 253, pl. ii, fig. 5) and especially appears to be identical with the variety *belliloci* described by Rigaux from Ferques (1908, p. 19, pl. i, fig. 6) and mentioned by Asselberghs (1912, pp. 10–12, t. 1, fig. 10) as characteristic of the Frasnian. Müller (1929, p. 261, t. 3, figs. 10*a–g*), has given a fuller account of the species and its varieties from the Frasnian of Almaden, Spain. Barrois (1882, p. 259, pl. x, fig. 4) regarded *S. comprimatus* Schlotheim as probably identical with Murchison's species.

This first figured specimen [H. 263] from Poleshill is quite distinct from the other specimen [H. 264] (fig. 11) from Poleshill, which is referred also to *Spiriferina cristata* var. *octoplicata* and apparently belongs to that genus, but doubtfully to that species and variety. *S. bouchardi* has several more ribs on each side of the median sinus, though of the 9 or 10 which can be counted the last 2 or 3 adjacent to the hinge-line are very small; there is also a median short weak rib in the middle of the sinus as Murchison and Rigaux mention, and there is no punctation of the shell. The strong concentric lamellation of the surface is well preserved in Whidborne's specimen, which as stated is only the impression of a pedicle-valve. We do not know the internal characters of *S. bouchardi*, but we may place it in the subgenus *Gürichella* Paeckelmann (1931, p. 299) which comprises the *Spirifer bifidus* group of species, and *S.* (*G.*) *angustisellatus* Paeckelmann (1913, p. 301, t. vii, figs. 5–6) bears a considerable resemblance, especially in the shape of the shell and median rib in the sinus, as does also *S. mesacostalis* Hall, as figured by Clarke and Swartz (1913, p. 601, pl. lviii, fig. 15 mon cet) from the Upper Devonian of Maryland and by Frech (1916, p. 217, t. 1, fig. 10) from the Middle Upper Devonian of the Taurus ; Frech remarked in a footnote on its resemblance to Paeckelmann's species. *S.* (" *Delthyris* ") *sculptilis* Hall, as figured and described by Hall and Kindle (Hall, 1867, p. 221, pl. 35, figs. 10–14 ; Kindle, 1900, p. 608, pl. x, fig. 2), from the Hamilton Formation of the United States may also be compared.

Spirifer (*Gürichella*) *obliteratus* Phillips var. nov. *brushfordensis*

The specimen [H. 258] of a brachial valve from Ashhill Quarry near Brushford figured by Whidborne (1897, p. 156, pl. xix, fig. 3) as *S. obliteratus* Phillips (1841, p. 78, pl. 31, fig. 135) is more acutely fusiform and more transverse than Phillips' type, being about three times as wide as long, and for these reasons we must regard it as a variety. It shows a very low median fold composed of a pair of rounded ribs and is separated from the lateral lobes by a deep wide groove on each side ; there are 12–14 low rounded closely placed costae on each lateral lobe becoming successively fainter and more indistinct towards the lateral angles. A thin median septum about one-third the length of the valve is present.

This species resembles the Devonian species *S. mucronatus* Conrad (Raymond, 1904, p. 296, pl. xvi, row 2), *S. mesacostalis* Hall (1867, p. 240, pl. xl, figs. 1–3), and *S. bimesialis* Hall (1858, p. 507, pl. iv, fig. 6) in the duplicate character of the median fold, but in shape and ribbing is most like the first of these species from the Chemung Group which Schuchert (1897, p. 207) put in the genus *Delthyris*. The Mississippian species *S. biplicoides* Weller (1914, p. 323, pl. xxxix, figs. 27–30) is also allied. Whidborne was of the opinion that *S. obliteratus* Phillips was possibly only a variety of *S. bouchardi*, but his figured specimen above described from Ashhill Quarry bears little resemblance to it.

Dimensions.

Length . .	8·5 mm.
Width . .	25·0 mm.

Subgenus : CYRTOSPIRIFER Nalivkin

Spirifer (*Cyrtospirifer*) *verneuili* Murchison var. nov. *guttata*

In the impression of the surface of the small pedicle-valve [H. 257] from Snapper Quarry, figured by Whidborne (1897, p. 152, pl. xviii, figs. 13, 13*a*) as *S. verneuili* Murchison, the enlargement of the surface ornamentation which he gave on fig. 13*a* makes the lachrymiform recumbent pustules on the ribs look like elongated pits and indeed he wrongly described them as pores, not recognizing that in the impression pustules would appear as small hollows. Although in all essential characters this shell agrees with *S. verneuili* or one of its many varieties, yet this pustulose ornamentation of the ribs is peculiar and resembles that of some members of the *ostiolati* group of the genus as defined by Hall and Clarke (1894, p. 28) ; but that group has the fold and sinus smooth and without ribs. In *S. verneuili* the ribs are usually quite smooth or only crossed by concentric lines as Gosselet has pointed out, and

Whidborne himself doubted if all the Pilton specimens belonged to this species. The present author (1922, p. 65), in describing the varieties of *S. verneuili* from the Upper Devonian of the Pamirs, remarked on the above-mentioned features in the specimen from Snapper Quarry and drew attention to the pustulose ornamentation found in some examples of the allied *S. whitneyi* Hall, var. *monticola* Haynes (1916, p. 37, pl. v, figs. 7, 8, 9) from the Upper Devonian of Montana, but in Whidborne's figured specimen the pustules are further apart and do not merge into radial lines. The varietal name *guttata* is therefore proposed for this Devonshire form. The author has previously described a somewhat similarly ornamented variety from Chitral under the varietal name *mastujensis* (1922, p. 63, pl. xii, figs. 6–10). Apart from this minor pustulose ornamentation Whidborne's specimen agrees with Dehée's *S. verneuili* from Etroeungt (1929, p. 18, pl. iii, figs. 1–3). Nalivkin (1930, pp. 123, 198) took *S. verneuili* as the type of his subgenus *Cyrtospirifer*, but there is much dufference of opinion about the classification of the species of the genus *Spirifer* and the value of the subgeneric groups.

Subgenus : CYRTIA Dalman

Spirifer (*Cyrtia*) *disjunctus* Sowerby

It seems to the present author that the common British Upper Devonian shell which Sowerby (1840, pl. 53, fig. 8, pl. 54, figs. 12, 13) named *S. disjunctus* is not a synonym of the typical *S. verneuili* Murch., though this identification has been generally accepted, Murchison's name having the priority. An examination has been made of a large series of undistorted and uncrushed specimens from the Pilton beds as well as of Whidborne's other specimens [H. 255–6] which he ascribed to *S. verneuili* (1897, pl. xviii, figs. 9, 10) and they are seen to exhibit several important differences from that species ; the hinge-area of the pedicle-valve is much larger and flatter and is inclined nearly at right angles to the valve ; the umbo of this valve is also not so much elevated or incurved, and the ribs are fewer in number, and this corresponds to the variety *barumensis* Salter (Davidson, 1866, p. 154). The absence of pustulose ornamentation on the ribs which are smooth in this Pilton form can only be regarded as of varietal value. Hall and Clarke (1894, p. 42) remark that *S. disjunctus* belongs to the *Cyrtia* group of *Spirifer* and is allied to *C. alta* Hall (1867, p. 248, pl. 43, figs. 1–7 ; Prosser, 1912, p. 536, pl. xxx, figs. 1–4) of the Chemung formation, and consider it distinct from *S. whitneyi* Hall, which is clearly allied to the typical *S. verneuili* Murchison. The view as to the specific individuality of *S. disjunctus* and *S. verneuili* has been widely disputed, and in the literature of the subject they are usually considered to be inseparable, though chiefly on the assumption that *S. verneuili* is a very variable form. But it appears necessary to accord them specific if not subgeneric distinction. A full dissertation on the various views of the subject has been given by Peetz (1901, pp. 94–104) and more recently by Grabau (1931, pp. 231–241) who would put, however, the Chinese shells usually identified with *S. disjunctus* into his new subgenus *Sinospirifer*, but he keeps *S. verneuili* (Grabau, p. 227) as a separate species together with *S. lonsdalei* Murchison and *S. whitneyi* Hall. It seems hardly possible to separate the Etroeungt species *S. julii* Dehée (1929, p. 19, pl. ii, figs. 1–8) from typical examples of *S. disjunctus* from Devonshire.

The presence of ribs, though often faint, on the median fold of the brachial valve and in the sinus of the pedicle-valve is an external feature distinguishing Sowerby's and Dehée's species from the Carboniferous genera *Syringothyris* and *Pseudosyrinx* and from the Upper Devonian genus *Platyrachella* Fenton (1924, p. 158). In a recent paper George (1933, pp. 423–456) has discussed the various classifications and genera or subgenera of the Spiriferidae which have been put forward, but there is as stated no general agreement on the matter.

Genus : RETICULARIA McCoy

Reticularia whidbornei sp. nov.

The impression of the exterior of a transversely subcircular moderately convex brachial ? valve [H. 254] with only traces of a low rounded median fold and having regular concentric rather wide equidistant concentrically striated or smooth lamellae armed on the edge with numerous small slightly elongated pustules was figured by Whidborne (1897, p. 151, pl. xviii, figs. 7, 7*a*) as *Spirifer microgemma* Phillips (1841, p. 68, pl. 27, figs. 116*a*, *b*). But Phillips' description and figures do not agree in the case of the ornamentation, for he states that " the surface [is] thickly and finely striated from the beaks, the striae being crossed by rather conspicuous laminae of growth ; at the intersections of these two sets of lines [there] are minute regular round eminences ", and these features are plainly shown in his figures and in Davidson's reproduction of one of them (1865, pl. iv, fig. 16). As regards the internal characters of Phillips' type nothing is known, but Whidborne says that one internal cast from Pilton shows arching dental plates and that in another the spines are bicanaliculate, though in the figured specimen they seem to be uniramous. These features the author has not been able to verify, and the interior of Whidborne's figured specimen are unknown. Owing to the difference in the ornamentation of the shell we can hardly put it in the same species as *S. microgemma*, for there is no trace of any radial striae on our specimen, the lamellae being smooth or concentrically striated as above stated. It seems much to resemble *Reticularia spinosa* Kindle (1909, p. 27, pl. ix, figs. 4, 5) from the Ouray Limestone of Colorado and *R. setigera* (Hall) (1858, p. 705, pl. 27, fig. 4) of the Lower Carboniferous of America (Weller, 1914, p. 431, pl. lxxiv, figs. 12–22) and *R. praematura* (Hall) (1867, p. 250, pl. 33, figs. 31–35) of the Chemung Group, but probably it is a new species to which the name *whidbornei* may be suitably attached.

Subgenus : RETICULARIOPSIS Fredericks

Reticularia (*Reticulariopsis* ?) *microgemma* (Phillips) var. nov. *tenuistriata*

The impression of the exterior of a fragment of the marginal portion of a distorted valve [H. 253] from Pilton which Whidborne figured (1897, pl. xx, fig. 2) as *Athyris roissyi* L'Éveillé can hardly be attributed to that species or genus, for the surface is covered with fine equidistant radial lines along which are set small spinules or tubercles at their intersection with the concentric closely placed and mostly equidistant thin lamellae, which become less regular and slightly undulating near the margin ; the interspaces between the radial lines are much wider than the radial lines themselves and are crossed by the concentric lamellae, as Whidborne's small figure of a portion of the surface shows. This type of ornamentation agrees with that of Phillips' *Spirifera microgemma* (1841, pl. 27, fig. 116), and the first specimen figured by Sowerby (1840, pl. 56, fig. 10, non 11) as *Strigocephalus* [sic] *giganteus* appears to have the same character. But the ornamentation in Whidborne's specimen is much finer than in *S. microgemma* Phillips and it must be separated from that species, at any rate, as a variety which may be named *tenuistriata*. Davidson (1865, p. 45, pl. iv, fig. 16) regarded Phillips' species as probably inseparable from the Carboniferous *R. lineata* (Martin), but Whidborne's Devonian specimen seems more like *R. pseudolineata* (Hall) (1858, p. 645, pl. 20, fig. 4) of the Lower Carboniferous of the United States. We may probably put Phillips' species in Fredericks' genus *Reticulariopsis* which we prefer to regard as of subgeneric rather than of generic rank.

(*To be concluded*)

Transgressive Upper Eocene in Palestine

By M. AVNIMELECH

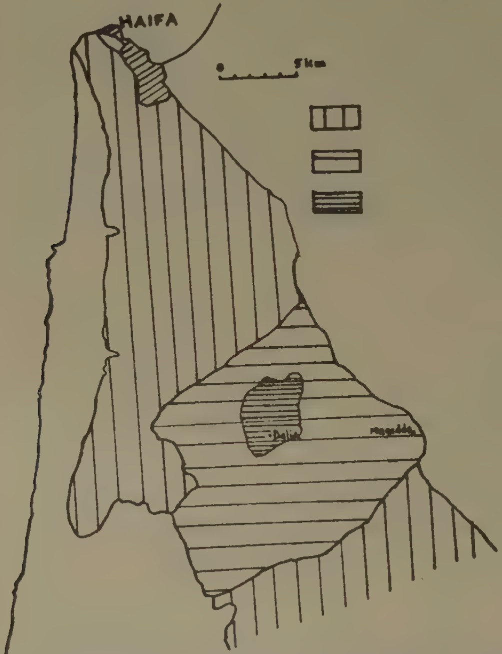
SEVERAL years ago I wrote a number of papers on the results of my investigations in a synclinal area near Megiddo, south-east of Mount Carmel, which I called " the syncline of Megiddo ". In the thick Eocene series of this syncline two distinct horizons of Lower and Upper Lutetian have been recognized. Above the Lutetian beds some patches of transgressive Upper Oligocene are preserved. Unfortunately the publications were based on investigations of only the north-eastern border of the whole synclinal region, further field explorations having been made impossible by the riots in 1936–39. In the summer of 1942 I renewed my fieldwork, which has led to a discovery of an Upper Eocene transgression over a probable Middle Eocene series.

Upper Eocene has already been reported from Palestine by several authors. The claims of older authors, like Blanckenhorn, were not sufficiently justified by palaeontological evidence, and the rocks in question have lately been recognized as belonging mostly to Upper Oligocene (Blanckenhorn, 1890, 1931, 1935; Cox, 1934; Blake, 1935, 1939; Henson, 1937). In Southern Palestine, in the area round Beersheba, the existence of Upper Eocene was proved by microforaminiferal study of boring-samples, but from the report of Blake (1935) it is not sufficiently clear whether the sequence may be considered as continuous or whether an unconformity separates the Upper Eocene from Lutetian beds. Picard and Solomonica (1936) studying the Eocene-Oligocene formations in the Beit-Jibrin (Bet-Govrin) area (west of Hebron), concluded that the sedimentation was continuous from the Upper Cretaceous to the Upper Oligocene, but they did not mention any palaeontological material from Upper Eocene. On the contrary Upper Eocene was definitely proved for Northern Palestine by finding *Camerina incrassata* (de la Harpe) in limestone beds of Kfar Hassidim, a locality some 10 km. S.E. of Haifa (Picard and Doncieux, 1937). Simultaneously Blake (1937) mentioned the existence of Upper Eocene near Bassa, on the Lebanon frontier, without giving any stratigraphical or palaeontological details. In a generalized way the Eocene was dealt with in Blake's *Geological Map of Palestine* (1939), where vast parts of the country are designated as of Upper-Middle Eocene.

The more recent investigations of the Eocene in Syria show that the Upper Eocene horizon is distributed over large areas. Mme de Cizancourt (1934) reports on *Camerina* cf. *incrassata* found together with *C. bouillei* in Wadi Souab, a southern affluent of the Euphrates (Jezira district of Syria). Dubertret and his collaborators (1938), discovered Upper Eocene, sufficiently proved by a *Camerina*-fauna, west and north of Damascus and south of Antiochia. Discussing the relations of this Upper Eocene to the Lower and Upper Lutetian the authors concluded that in the time between Lower Lutetian and Upper Oligocene the present mountains were already in a state of emergence.

With this information the discovery of clearly transgressive Upper Eocene in the Megiddo syncline is not only of local but also of general interest. This Upper Eocene is situated on and around Dalia area (near Daliyat ar Rauha), a settlement some 25 km. S.S.E. of Haifa, nearly in the middle of the syncline. It lies on the monotonous, uniform *Globigerina* limestone and flint of the assumed Lutetian. Clearly recognizable Upper Lutetian beds, containing numerous *Camerina gizehensis curvispira* are found some 4 km. east in a similar lithological series of *Globigerina*-limestones and cherts.

Physical discordance between the two series is often difficult to detect as both have only a slight dip. The transgressive series usually begins with conglomerates, but often the size of their elements is very small and uniformly silicified. The detrital character is found in almost the whole series, but the conglomerates are especially well developed in the upper part of the series. Generally a lower and an upper conglomerate horizon may be distinguished.



SKETCH MAP SHOWING THE SITUATION OF UPPER EOCENE OUTCROPS.

Palaeontologically this transgressive Upper Eocene is characterized by the appearance of *Camerina incrassata*, *C. striata*, *C. bouillei*, and by *Asterocyclina stellaris* ; the absence of *C. gizehensis* must be also noted. *Camerina incrassata* and *bouillei* may of course be of Oligocene age also, but the presence of *C. striata* and especially of *Asterocyclina stellaris* does not admit of an age other than the Upper Eocene, e.g. the Priabonian, perhaps Upper Priabonian if compared with the occurrence in the

Vicentian basin (Douvillé, 1922) or with the occurrence in N.W. Morocco (Brönnimann, 1938). At one point an isolated exposure, probaby belonging to the upper conglomerate zone, filled with *Asterocyclina stella* but without *A. stellaris,* was found. This may point to the existence of an older horizon—probably of Lower Priabonian age (Lower Ledian of Brönnimann, 1938)—which was destroyed by the transgression of the Upper Priabonain sea. Another formation, which is evidently older than Upper Priabonian, presents a quite hard, compact, white-grey microforaminiferal limestone with brown chert nodules, containing casts of small gastropods of *Rissoa* type and sometimes casts of "*Cerithium*". This, gastropod-bearing limestone and chert is the principal constituent of the upper conglomerate horizon.

The facies of our Priabonian changes greatly in both horizontal and vertical directions. The changes are both lithological and faunal. There are here represented chalky *Globigerina*-limestones and cherts, limestones and cherts rich in microforaminifera, marmorized *Camerina*-limestones, glauconitic *Camerina* limestones and cherts, *Asterocyclina*-limestones, siliceous *Asterocyclina* limestones and cherts.

The surface of transgression was deeply eroded as can be seen, for instance, on the Es Sillama hill in the western part of Dalia area, where on the southern (50 m. high) slope a Priabonian series 30 m. thick is observed, of which nothing may be seen on the northern slope, although the strike-direction of the layers is here N.-S. Consequently the extension of particular stages varies, and there is also a great difference in every section. Only in a few places may a complete section be observed, and in many others only the upper conglomerates are present, lying directly on the Lutetian *Globigerina* series (for instance in Wadi Rushrasha west of Ar Rihaniya).

The most important conclusion which may now be drawn is that after Upper Lutetian times a general retreat of the sea took place over a very large area of Palestine and the neighbouring countries. This was connected, of course, with the continuous folding movements. After a relatively short interval the sea returned, but this time did not attain its former extent, in Palestine evidently reaching only the western parts of the country and not covering several emergent blocks of rising mountains. In Syria the area covered by Priabonian sea was much greater, extending as far as Damascus and Jezira regions, but here also some small areas stood up above the sea.

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Problems of Ammonite Nomenclature

VIII. On *Ammonites cordatus* and *A. serratus*, J. Sowerby

By L. F. Spath

THE International Rules of Zoological Nomenclature aim at the "elimination of all possibilities of discussion"; and in troubled times like the present, when it is impossible to secure decision on a knotty problem by the International Commission, automatic solution of any nomenclatorial difficulty should be particularly welcome. We all know of certain genera that have caused trouble to revisers because they were based on several species, subsequently found to belong to more than one genus; likewise species have often been based on a number of differing specimens, some of which have in course of time been relegated to other species or genera. Now Opinion 88 claims that the procedure to be followed in such cases is well known, but on this point there appears to be some doubt, and I therefore propose to discuss the two species mentioned in the above title.[1]

According to Opinion 6, when a later author divides a genus (A) with two species (Ab, Ac) into two separate genera (A, C) leaving species Ab in the first genus A and putting species Cc into the second, monotypic genus C, he is to be construed as having also fixed the type of the first genus A. Let it be noted at once that it makes no difference whether we deal with genera or species; for in accordance with Article 31 the division of a species into two or more restricted species is subject to the same rules as the division of a genus. The meaning of the expression "select the type" is therefore to be as rigidly construed in the case of a species as in the case of a genus.

Since the names *Amm. cordatus* and *Amm. serratus*, as originally put forward by Sowerby, were both applied to two distinct forms which have been separated by later authors, they come under the ruling just cited. By renaming one of Sowerby's examples of *Amm. cordatus*, Pavlov[2] and later Buckman[3] automatically restricted the species to the second specimen; but the case is still more simplified by the fact that one of the two original examples of *Amm. cordatus* was only doubtfully referred to it by the author. According to Art. 30, iie, γ, it is excluded from consideration in determining the type and Sowerby's two specimens are not even syntypes. As Healey[4] and Crick[5] recognized, therefore, the original of Sowerby's fig. 2 has always been the holotype of *Amm. cordatus* and is not "subject to change"; the species being, in fact, monotypic, no original or subsequent verbal designation was necessary.

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[1] Both were described in 1813 in vol. i of *Mineral Conchology*, p. 51, pl. xvii, figs. 2 and 4 (*Amm. cordatus*) and p. 65, pl. xxiv (*Amm. serratus*).

[2] Les Céphalopodes du Jura et du Crétacé inférieur de la Sibérie septentrionale. *Mém. Acad. Sci. St. Pétersb.*, ser. viii, xxi, No. 4, 1914, 48.

[3] *Type Ammonites*, iii, 1920, 10, 15. I am using *Cardioceras cardia* Buckman in preference to *C. subcordatum*, Pavlov, because *Amm. subcordatus*, d'Orbigny, is also a *Cardioceras* in continental literature, and it would be very misleading to use *subcordatum* as a zonal or sub-zonal index (Spath, 1935, p. 15).

[4] *Pal. Universalis*, ser. ii, fasc. 1, 1905, Nos. 94, 94*a*.

[5] Note on the Type-specimens of *Amm. cordatus* and *Amm. excavatus*, J. Sowerby. *Geol. Mag.*, xlvii, 1910, 503–5.

Arkell[1] is wrong in thinking that "Buckman had no right to rename either of Sowerby's specimens without first designating a lectotype"; he is wrong in excluding from *Amm. cordatus* the specimen which Healey, Crick, and Buckman accepted as the type of that species, and it is irrelevant how these authors interpreted it.

The case is so plain that I should not have considered it necessary to revert to it[2] had it not been suggested repeatedly by Arkell[3] that there might be "divergent interpretation" of this species, and had he not again spoken of Sowerby's fig. 4 as the "true" *Cardioceras cordatum.*

The case of *Amm. serratus* may appear to be slightly more complicated, in so far as the species was based on three specimens, and a first doubt could arise whether only two forms are represented. The point is of importance because if three forms are to be divided in a genus or species, instead of two, as envisaged in Opinion 6, above cited, the procedure is rather different. That is to say if two species (Ab and Ad) are left in genus A, and Cc, as before, is put into a separate genus C, then a future reviser of A is not, as might be thought, prevented from designating Cc as the lectotype of A. However illogical this may seem, the fact that three instead of two forms are involved immediately puts the case on a different footing. The "selection of a type by elimination" is now made the subject only of an unenforceable "Recommendation" (Art. 30, iii, k). But whereas this merely suggests that "preference should be shown" to the species not assigned to other genera, matters are rather aggravated by Opinion 62. This is an altogether more undesirable ruling than the inconclusive "Recommendation", and may justify a slight digression.

Opinion 62 holds, first of all, that the fact that a species has already been made the type of another genus does not exclude it from consideration in selecting it as type (of the original genus). We have already seen that Opinion 6 says that it does, at least when there are only two species; so we conclude that the framers of Opinion 62 had overlooked the existence of the earlier Opinion 6. But, as I pointed out before in this series, in connection with the genus *Rhacophyllites*,[4] there are grave objections to the automatic support given by this ruling to the careless or ill-informed reviser's selection, and the overriding of previous work. For a genus has a biological as well as a nomenclatorial standing, and the former cannot be so objectively determined as the latter. The danger apprehended by the Commission that types might otherwise be "subject to change" is present all the time; several Opinions remind us that, if it should be discovered in the future that a now unknown author has already designated another type, or if a species is rendered unavailable "by being a homonym, or for other cause", a change would be necessary.

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[1] The Ammonite Zones of the Upper Oxfordian of Oxford, and the Horizons of the Sowerby's and Buckman's Types. *Quart. Journ. Geol. Soc.*, xcii, 1936, 152. See also *Monograph Corallian Ammonites*, pt. viii, 1942, 243.

[2] See Spath, The Ammonite Zones of the Upper Oxford Clay of Warboys, Huntingdonshire. *Bull. Geol. Surv.*, No. 1, 1939, 88 (footnote 1).

[3] The Upper Oxford Clay at Purton, Wilts, and the Zones of the Lower Oxfordian. *Geol. Mag.*, lxxviii, 1941, 169.

[4] See No. iv of this series, *Geol. Mag.*, lxxvi, 1939, 77.

Opinions are given only " on the premises submitted " or " upon the data presented ", often necessarily incomplete ; hence the types of genera not yet placed in the " Official List " are always " subject to change ". Moreover, if, as Opinion 101 holds, it is incumbent upon an author who proposes new names to familiarize himself with, and reasonably apply, the rules of zoological nomenclature (the Recommendations he may flout) it seems illogical to decree that he may designate types " in ignorance of previous action of others or without knowledge of the previous literature or any similar reason " (Opinion 62). But such is the purely nomenclatorial attitude of the Rules.

Whatever may be decided in the future with regard to stabilizing the selection of types by elimination, there can be no doubt that Opinion 6 is binding in the case of a genus with only two species or of a species with two differing syntypes. Now in *Amm. serratus*, although there are two specimens and a fragment, no one has yet claimed that more than two species are involved ; so there is no complication, but a further point should here be considered. Of the three illustrations, the upper figure, representing a well recognizable ammonite, is good, even by modern standards ; the lower figure shows a worn and all but unrecognizable cast of an ammonite ; and the middle figure represents merely a septal surface of a small whorl-fragment. It is not difficult to see which of the three depicts the species referred to in the description [1] ; but again we are in doubt as to the procedure. For it has been considered unnecessary to stipulate in the Rules that when a species has been described and illustrated by two or more figures, only one of which shows the specific characters mentioned in the description, then the species is to be interpreted by that one figure. However desirable it may be that that figure should automatically become the type figure, at present there seems to be nothing but another " Recommendation " to stop the transposition of a specific name, by selecting as the type some unrepresentative syntype in preference to the obvious example.

My own interpretation of Sowerby's figures of *Amm. serratus* is that the cross-section (i.e. the middle figure), on account of its " protuberating undulations outside " represents the same species as the upper figure, and that the lower figure is probably the same form as that described by Buckman [2] as *Prionodoceras prionodes*, though it cannot be identified with certainty. Arkell,[3] so far, seems to agree ; but he writes " if Sowerby's [upper] figure is accurate, *Amm. serratus*, so interpreted, would be a very rare species ; indeed, I know of no specimens like it ". There is no reason to doubt the general accuracy of the figure which can be matched by specimens, even if Arkell has not seen any ; and it is irrelevant whether the species is rare or not.[1]

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[1] I.e. a form having the characteristic undulations near the circumference, persisting to about 75 mm. diameter (the figure is slightly reduced) and a five-angled cross-section. The ribbing on the inner whorls is the same in all the forms of *Prionodoceras* from the *serratus* zone.

[2] *Type Ammonites*, iii, 1920, pl. 155 (" *Prionoceras* "). Buckman's *P. excentricum* (ibid., v, 1924, pl. 464) seems to be merely an individual variation of *P. prionodes*.

[3] Report on Ammonites collected at Long Stanton, Cambs., and on the Age of the Ampthill Clay. *Summ. Progr. Geol. Survey for* 1935, pt. ii (1937), 67. Also : *Monograph on the Ammonites of the English Corallian Beds*, pt. iii, Pal. Soc., 1937, 50.

Sowerby's lower figure, in Arkell's view, " seems to represent the common smooth form," and he therefore designated it as lectotype. But how uncertain he was about the validity of this selection is evident from the fact that, later in 1937, he proposed an alternative designation. " Failing that," he wrote, " I designate as neotype . . . an example figured by Salfeld." [2] The latter, however, falls within the same smooth form that had already been named by Buckman. Arkell, then, is not merely attempting to substitute for a well-ornamented species a smooth form, incompatible with the description, but he is selecting as typical a form that had already been excluded by elimination. In accordance with Opinion 6 Buckman must be construed as having fixed the type of *Amm. serratus* by giving a separate name to the smooth form which includes Sowerby's lower figure and certainly Salfeld's figure above cited. As Opinion 6 states, it is hard to conceive of a more effective way to designate, or select a type (than by elimination of the only rival) ; in other words by the division of the species it was made monotypic.

No special designation, of course, was required when I myself [3] recently had occasion to revise this group. Arkell's objection to my " seeking to restrict the name *serratum* to the upper of Sowerby's figures and calling the common smooth form, represented in the lower figure, *prionodes* (Buckman) ", seems to be based on a fear that I was " thereby virtually suppressing the name *serratum* current for over a hundred years ". As regards the inconspicuous part played by that species [4] in literature during the first century of its existence, I do not propose to weary the reader with the facts, but they make a sorry tale of misidentification, from J. de C. Sowerby [5] onwards, and of neglect by authors who created allied or identical species. I certainly cannot admit that the restriction upsets current nomenclature, for down to the end of last century there was uncertainty about the affinities of *Amm. serratus* (which was generally identified with either *Amm. alternans* or *Amm. excavatus*) as well as about its bed (Oxford Clay in Crick [6] and H. B. Woodward,[7] Ampthill

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[1] Blake, in 1875, spoke of *Amm. serratus* as being " plentiful ", and he recorded a peculiar form of that species " like Sowerby's original ", occurring " in abundance " in Lincolnshire. Elsewhere, he spoke of *Amm. serratus* " of the Sowerbyan form " in Yorkshire (On the Kimmeridge Clay of England. *Quart. Journ. Geol. Soc.*, xxxi, 1875, 208, 209, 210).

[2] Monographie der Gattung *Cardioceras*. I. *Zeit. Deutsch. Geol. Ges.*, lxvii, 1915, 172–5, pl. xviii, figs. 1*a–c*.

[3] The Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land. I. Oxfordian and Lower Kimmeridgian. *Medd. om Grønland*, 99, No. 2, 1935, 12–25.

[4] A rival *Amm. serratus* was created by Parkinson in 1819.

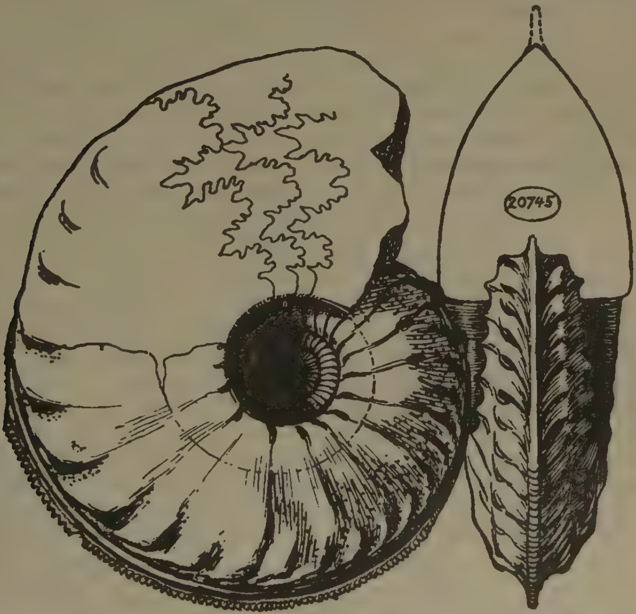
[5] A specimen of *Amm. serratus* (B.M. No. 66341) bears his own identification " *Amm. stokesi*, M.C. 191 ", which is interesting in view of the fact that Roemer (1836) united *Amm. serratus* with *Amm. amaltheus*, Schlotheim (i.e. the German equivalent of *Amm. stokesi*).

[6] On the Muscular Attachment of the Animal to its Shell in some Fossil Cephalopoda (Ammonoidea). *Trans. Linn. Soc.*, 2nd ser., Zool., vii, pt. 4, 1898, 75, 86, pl. xviii, figs. 8–10, pl. xix, figs. 1, 2.

[7] Jurassic Rocks of Britain, V. *Mem. Geol. Surv.*, 1895, p. 56 (cited as *Amm. cordatus*, var. *excavatus*).

Clay in Roberts,[1] Kimmeridge Clay in Damon[2]). Almost as soon as Salfeld's work became available, Buckman divided the species. It is wrong to say that Salfeld " fixed the species *serratum* once and for all " ; he certainly included in it the original of Sowerby's upper figure (" with the test preserved "), and what have since been separated as a number of distinct species of *Prionodoceras*.

These include, for example, *P. truculentum*, Buckman,[3] which is based on a coarsely ornamented individual of *Amm. serratus*, and, to my mind, is scarcely specifically separable, as a comparison of Buckman's figure with what I consider to be a typical example of *Amoeboceras* (*Prionodoceras*) *serratum*, represented in Text-fig. 1, will show. Sowerby's drawing is reduced, so there is little difference in size between the two specimens ; and if the casts of a few more camerae had been allowed to remain[4] on the neotype now figured, agreement would be almost perfect. For these camerae would have covered the last few lateral tubercles and the end of the " bifurcating " stage, but the absence of primary ribs and umbilical nodes on the outer whorl of Sowerby's specimen is due to the mode of preservation. In many of the Drift specimens of the *serratus* group the chalky test is easily removed, and when it is missing on the inner half



TEXT-FIG. 1.—*Amoeboceras* (*Prionodoceras*) *serratum* (J. Sowerby). Drift (ex Ampthill Clay), Bugbrook, Northants. (B.M., No. 20745*b*.) Neotype. (Reduced × 0·9).

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[1] *The Jurassic Rocks of the Neighbourhood of Cambridge*, 1892, p. 50.

[2] *Supplement to the Geology of Weymouth*, 1888, pl. xv, fig. 5.

[3] *Type Ammonites*, vi, 1927, pl. 704.

[4] The presence of glue on the last septal surface shows that part of the outer whorl has been detached and apparently discarded.

of the whorl-side, between the line of involution and the umbilicus, the primary ribs may look inconspicuous. The width of the umbilicus is 22 per cent in the neotype, 23 per cent in Sowerby's figure, but only 21 per cent in other examples.

As may be expected, not every individual lost its ribs and tubercles at exactly the same size as the neotype or Sowerby's example ; the decline in strength of the outer nodes also may be less rapid or less conspicuous. For instance the specimen identified by J. de C. Sowerby with *Amm. stokesi*, above referred to, is slightly coarser, with the outer nodes persisting to about 90 mm. diameter, so that it might be included in *A.* (*P.*), *truculentum*. It still has indistinct, but more closely set nodes at 115 mm. at about the middle of the body-chamber (the present end of the ammonite) ; another complete specimen (No. C. 26246) is nodate throughout, to 175 mm. diameter. In still another example (No. C. 39651) of the same form, even the lateral tubercle (of the " bifurcating " stage) is still prominent at 85 mm. diameter.[1] Yet another specimen (No. 43978*a*), bearing Sowerby's identification, is very typical and at first was thought to be the missing type of *A.* (*P.*) *serratum*, Sowerby's figure being presumably reversed ; but the secondaries are slightly less prominent. The serrations of the keel also do not agree, but there may be considerable variation in this character, even in the same specimen.

Another of the examples in the Sowerby Collection (No. 43978*b*) has still closer outer ribs and, like various other specimens before me, is transitional to *A.* (*P.*) *glosense* (Bigot and Brasil).[2] There are also a compressed variety (No. C. 16231), an evolute variety with very coarse keel (No. C. 39517), and several direct transitions to *A.* (*P.*) *prionodes*, S. Buckman sp. (e.g. Nos. C. 39661, 39662, L.F.S. 868,869).

Cardioceras shuravskii, Sokolov,[3] which is another form of the *serratus* group that was very widely interpreted by its author, differs from Sowerby's species chiefly in its slightly wider umbilicus and in its finer secondary ribs, after the disappearance of the primaries ; but it could almost be included in *A.* (*P.*) *serratum* as another variety, because there is less difference between the neotype of the latter species and the lectotype of *A.* (*P.*) *shuravskii* than there is between that and the original of Sokolov's fig. 5 (apparently a transition of *A.* (*P.*) *prionodes*, almost indistinguishable from the Drift example No. C. 39662, above cited).

The holotype of *A.* (*P.*) *glosense* already mentioned, is slightly deformed, so that the peripheral aspect of the earlier half of the outer whorl appears too compressed. The species occurs in the English Drift (Nos. 998, 20131) and is connected by various passage-forms (e.g. Nos. 20897, 89070, C. 10628) with *A.* (*P.*) *serratum* and *A.* (*P.*) *truculentum*. There are coarse examples (e.g. No. 37439) in which what may be called the " trituberculate " stage persists to about 90 mm. diameter ; the finer and closer ribs, it is true, give these transitions a somewhat different appearance, but it is a difference only of degree, not of kind. Other varieties (e.g. No. 20899) of *A.* (*P.*) *glosense* with 34 ribs (instead of 27) at 87 mm. diameter, are transitional towards *A.* (*P.*) *freboldi*, Spath,[1] and to yet other species, but they are all distinct from the example of *Amm. serratus*, figured by Damon, although Arkell refigured a plaster-cast of the latter as *A.* (*P.*) *glosensis*. I have long had by me a polished half of a Drift ammonite (L.F.S. No. 542) which is undoubtedly the same form as Damon's type, though the secondary ribs disappear just a trifle sooner. When I previously[2] referred to this form, I called it a variety of *A. serratum* or of *A. truculentum*, but with its long secondary ribs it is at least as distinct as some of the other variations of this group already discussed and may therefore be named *A.* (*P.*) **damoni**, nov.[3] for it is not the same as *A.* (*P.*) *glosense*. It is probably connected by transitions with the group of *A.* (*P.*) *alternoides* (Nikitin), but the description of some new material from East Greenland will provide a welcome opportunity to deal with the now rather numerous species of *Prionodoceras*.

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[1] The specimen is too badly corroded after that stage.

[2] Description de la Faune des Sables jurassiques supérieurs du Calvados. *Mém. Soc. Linn. Normandie*, xxi, 1904, 17, pl. 1 (iv), figs. 13, 13*a* (*Cardioceras alternans* var. *glosensis*).

[3] Zur Ammoniten-Fauna des Petschoraschen Jura. *Mém. Com. géol. St. Pétersb.* N.S., 76, 1912, 60, pl. ii, fig. 4 (lectotype).

In the meantime I may add that the sub-genus has a longer range than was previously suspected. Although it is common at the end of the Oxfordian (*serratum-truculentum* and *anglica-pseudocordata* zones),[4] *Prionodoceras* probably ranges up into the Lower Kimmeridgian, where it is gradually replaced by *Amoebites* and *Euprionoceras*.

REVIEW

CLIMATIC ACCIDENTS IN LANDSCAPE-MAKING. By C. A. COTTON. pp. xx + 343, with 58 plates and 149 Text-figures. Whitcomb and Tombs, Ltd., Wellington, etc., 1942. Price 30*s*.

It is stated on the title-page and in the preface that this book is really a sequel to the author's former work *Landscape*, which dealt with what is in it called normal erosion. A reviewer of the last-named book pointed out that there is really no reason why a damp-temperate climate should be considered as normal or standard. A precisely similar criticism applies, and perhaps even more forcibly, to the treatment of aridity as a geological accident, since probably quite as much of the land of the globe is arid as is damp-temperate, and possibly more. The other accident as here defined is glaciation, and for this there is perhaps more justification. Another great need in geology now is a collected and critical treatment of land-forms in the wet tropics (jungle country) where the dominant factors are intense chemical weathering, protection by vegetation and slipping of every degree from slow soil-creep to landslips on the largest scale.

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[1] *Op. cit.* (Milne Land, i), 1935, p. 25. The "trituberculate" stage in this species begins at a diameter at which *A.* (*P.*) *serratum* is already becoming smooth. The outer nodes are less projected than in *A.* (*P.*) *glosense*, more angular, and increase in prominence with age.

[2] Revision of the Jurassic Cephalopod Fauna of Kachh. *Mem. Geol. Surv. India, Pal. Indica.*, N.S., ix, No. 2, part vi, 1933, 863, 868.

[3] Type to be Damon's original in the British Museum (N.H. No. C. 3305); see footnote 2, p. 115.

[4] In the Table of Ammonite Zones given in 1935 (Spath, *op. cit.*, Milne Land, i, 74) the species of *Amoeboceras* of the *anglica* zone should have been *A. marstonense*, which is associated in the same bed with *A.* (*P.*) *ogivale*, Buckman sp. (*ibid.*, p. 18, footnote 1) and undescribed forms.

Apart from the foregoing criticism, which after all is only a matter of terminology, this book deserves only praise. The study of arid conditions is now attracting more and more attention, in view of the increasing economic importance of soil erosion, as the present writer has recently emphasized in a review of a South African book. Recent war news from North Africa must have familiarized even newspaper readers with the fact that in arid regions, actual deserts, it rains quite a lot at times, and that there is mud, as well as sand storms, sometimes apparently both at once. One notable point in Professor Cotton's account of erosion in arid regions is that he does not attribute much importance to wind as a cause of large scale denudation; he regards it, in common with Walther many years ago, as merely putting in a little sculptural detail, the ornament rather than the design of the denudational forms. Much use is here made for descriptive purposes of the conception of the pediment as a land-form. This term seems to have come to stay, unlike many geomorphological names. Much of the actual transport of material in arid regions is attributed to the sheet-flood, which seems to be much the same as what is best known to geologists as a cloud-burst.

There is a very interesting discussion of the Inselberg type of denudation, which cannot be dealt with in detail here. Even if such forms are to be mainly attributed to exfoliation, as is generally believed, it is not at all clear how this process actually works.

Rather less than two-thirds of the book deals with glaciation, and for this part of the subject New Zealand obviously provides a splendid series of examples. In the discussion on glacial erosion protectionist theories receive little sympathy, while a useful warning is given that some geologists when visiting a notoriously glaciated region such as the Alps have been too much inclined to attribute everything they saw to ice, without considering that the work of glaciers started on an already highly developed topography, much or most of which may have survived.

In his discussion of the difficult problem of the origin of cirques Professor Cotton accepts for the most part the idea of plucking in the bergschrund, as described by Willard Johnson, but he also insists on the necessity for a previously existing hollow of some sort, to allow of a sufficient accumulation of snow to start the process. As for the operation of ice-erosion in general and especially the overdeepening and widening of valleys, much importance is attached to the "freeze and thaw" theory which depends on the fact that the temperature at the base of the glacier is usually just above the freezing point. When it is too cold, nothing happens. It is even suggested that "freeze and thaw" at the bottom of a casual snow-drift may initiate the necessary hollows for cirque formation.

The book ends rather abruptly with a paragraph of eight lines on notches cut across spurs by ice-margin streams. One would have liked a little more about what might well be called "Kendall channels", and a couple of photographs of some of the splendid Yorkshire specimens would have formed a welcome addition to the series of plates, which include many very beautiful and striking pictures from various parts of the world. As is only natural, some of the best are from New Zealand.

R. H. R.

CORRESPONDENCE

MINERALIZATION OF PERMIAN ROCKS OF SOUTH DURHAM

SIRS,—Mr. Fowler's account (*Geol. Mag.*, lxxx, 41–51) makes it clear that the mineralization of the Magnesian Limestone of South Durham is on a greater scale than was formerly known. The genesis of these mineral-deposits is still in doubt. I wish here to present some evidence that has been overlooked. During a revision of the British Permian fishes I examined in all several hundred specimens, of which quite a number, mostly from the South Durham outcrops of the Marl Slate, were associated with some mineralization. Similar associations are found with some tetrapod remains. The minerals observed include sphalerite, galena, chalcopyrite, and malachite (which may be a weathering-product). So far as my recollection goes these minerals never replace bone, but occur, for example, between the dermal bones of the skull, etc. This suggests strongly that the primary deposition of the ores may have been due to the presence of decaying macerated organic tissues, perhaps with the aid of sulphur-bacteria. This would imply that some, at least, of the mineralizing agents affecting the Permian rocks were syngenetic.

Comparison with the German Kupferschiefer-Zechstein mineralization is interesting. The Kupferschiefer fishes are often mineralized ; ores of copper, sphalerite, and galena are involved, but a most interesting example, involving metallic silver, has been described by K. Wanderer (*S.B. Isis, Dresden*, 1931, p. 168). The older view that the contortions of these fossil fishes were due to copper poisoning has been controverted by the work of Weigelt (*Palaeobiol.*, 1928, i, 323) and Laatsch (*Palaeobiol.*, 1931, iv, 175). There is now very good evidence for syngenetic primary mineralization of the Kupferschiefer (e.g. Schneiderhöhn, 1921, *N. Jb. Geol. Min. Paläont.*, Beil. Bd. xlvii, 1, and 1926, *Metall u. Erz*, xxiii (N.F., xiv), 143 ; Trask, 1925, *Econ. Geol.* xx, 746, and literature quoted by them). The metalliferous ores were partly deposited (according to Schneiderhöhn and Hoffmann) from solutions by the action of sulphur-bacteria in foetid muds rich in decaying organic matter. Nevertheless there is evidence of a certain amount of later mobilization and migration, both within the Kupferschiefer, and to overlying strata. Secondary mobilization of other syngenetic sedimentary copper deposits, and their precipitation with epigenetic relationships, has been discussed also by Finch (in *Lindgren Mem. Vol.*, " Ore Deposits of the Western States," New York, 1933, p. 481). In the Kupferschiefer, tectonic disturbances (" Rücken ") are associated with " enrichment, impoverishment, or removal upward in adjacent beds " of the ores (quoted from Lindgren, *Mineral Deposits*, New York, 1913, p. 381).

The occurrence of detrital barytes and fluorite in Permian rocks in Westmorland and Durham, and the evidence in favour of at least some syngenetic primary mineralization discussed above, show that material was brought into this Permian sedimentation area from the eroded Pennine veins—whether entirely as clastic fragments or partly in solution does not matter. Later solution, migration, and re-deposition with epigenetic relationships may be responsible for many of the occurrences reported by Mr. Fowler, and there is thus no strong evidence that the Pennine mineralization was not completed before the Permian rocks were deposited. The Great Sulphur Vein was later than much of the mineralization, but Dunham's main conclusions (*Quart. Journn. Geol. Soc.*, xc, 689) are not seriously affected by the new observations.

I should like to correct the misleading " Lower Permian " applied to the Marl Slate and Magnesian Limestone ; the rocks are certainly of Upper Permian age, equivalent to the German Kupferschiefer and Zechstein (cf. Westoll, 1941, *Geol. Mag.*, lxxviii, 37).

T. S. WESTOLL.

MARISCHAL COLLEGE, ABERDEEN.
24th May, 1943.

THE CLEVELAND AXIS

SIR,—May I crave space for three comments :—

(1) Now that Dr. Rastall has established the existence of Yeovilian-Aalenian pebble beds exactly on the central line of the axis, he will have proved his case for movement of the axis if he can establish their absence on either side.

(2) If he has established that Callovian, Oxfordian, or Corallian Beds are involved in the anticline, all that he said about these formations in his article is still irrelevant, because it applied to their development throughout the Yorkshire basin.

(3) Since I do not admit that any facts yet published are inconsistent with my generalization (and (1) above, could not have been " brushed aside " ten years before it was published) my generalization was not sweeping according to Dr. Rastall's definition.

W. J. ARKELL.

HURSTCOTE, CUMNOR, OXFORD.
21st May, 1943.

The pebble-beds of the Dogger were described by Young and Bird in 1822 and by John Phillips in 1829. Later writers, especially Hudleston and the Geological Survey, confused the subject by persistently calling them concretions and nodules. Their true nature was pointed out by Kendall in 1902 and by myself in 1905.

Dr. Arkell has written more than once of the Jurassic passing over the Cleveland *anticline*. Now the main point of Lamplugh's discussion was that in the Jurassic Cleveland was a geosyncline. The pre-Permian and Tertiary anticlinal uplifts had nothing to do with the character of Jurassic sedimentation.

Since the Kellaways facies of the Oxfordian still exists in considerable force in the (Tertiary) syncline of North Cleveland and the Corallian rocks come within three or four miles of the central axis my discussion of these strata was completely relevant to my purpose, which was to show that the depression of the geosyncline was not uninterrupted.

R. H. RASTALL.

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The Age of the Reef-Limestones in the Lower Carboniferous of North Derbyshire

By DONALD PARKINSON

1. INTRODUCTION

SHIRLEY and Horsfield (1940) in describing the Carboniferous Limestone of the Castleton-Bradwell area in North Derbyshire submitted evidence that the richly fossiliferous rocks of B_2 age, the " Castleton reef knoll limestones lie with strong unconformity on the D_1–D_2 limestones, being piled against steep slopes or cliffs of Mid-Carboniferous age of at least 550 feet. The Nun Low limestones of P age follow with a similar relationship to the Castleton Limestones ".

Prior to the work of the above authors the Castleton reef-limestones were known to contain, in addition to their numerous brachiopods, a goniatite fauna of Upper Beyrichoceras (B_2) age (Bisat, 1934). They were also known from the work of J. W. Jackson (1927) to contain, at Treak Cliff and Peaks Hill, the D_2 coral *Palaeosmilia regia*. Jackson has more recently recorded (1941) the characteristic D_1 brachiopod *Cyrtina septosa* from the reef-limestones of Middle Hill. He concludes (1941, p. 245) that in the Castleton area there are lenticles of reef-limestone with P_1 goniatites in cherty limestone of D_2, that P_1 beds rest on reef-limestone of Upper B_2 age, and that below the Upper B_2 beds there are reef-limestones of D_1 age.

From evidence obtained in the Slaidburn district of north-west Yorkshire the present author (1936) correlated P_1 with D_2 and B_2 with D_1, and Hudson reached similar conclusions from work in the Craven area of north-west Yorkshire (1933, 1938, and other papers).

Shirley and Horsfield's conclusion that the B_2 Castleton reef-limestones lie unconformably on D_1 and D_2 is based on field relations disclosed by detailed mapping, which however appears to ignore considerations of palaeontology. Their interpretation of the stratigraphy, in fact, appears to set aside certain well-established laws and for that reason is suspect; it disregards the possibility of rapid facies changes; it ignores evidence from other areas of correlation of the goniatite time scale with the coral-brachiopod time scale, and it finally takes no account at all of the extensive brachiopod fauna in the rocks of disputed age in the Castleton district itself. Since goniatites and corals are of only local occurrence in the Castleton reef-limestone, and the brachiopods are distributed universally, it seems evident that some attempt should have been made to employ these forms in dating the rocks despite the admitted difficulty of using reef brachiopods as zonal indices.

The conclusions of Shirley and Horsfield seemed so startling, particularly in view of the paucity of faunal data, that the author decided to examine their evidence for unconformity in the field. The present paper is an account of his own tentative views of the geological sequence in a part of the area described by them.

The author's work has hitherto been confined mainly to an area about one mile long by half a mile wide lying along the north-western edge of the limestone massif, and extending from Windy Knoll in a south-westerly direction to the north-western slope of Eldon Hill (Text-fig. 1). It includes the knolls of Peaks Hill, Middle Hill, and Snelslow which are bounded on the north-west by Edale Shales and on the south-east by the plateau of D_1 limestone which rises to a height of over 1,500 feet at Eldon Hill.

In addition, certain other of the critical sections discussed by Shirley and Horsfield, in the Treak Cliff-Castleton district have been inspected, some of them in the company of Dr. A. Lamont.

2. Reef and Associated Facies

A reef facies may be defined as a limestone deposit of limited extent, which is characterized by a lack of bedding, and by the presence of a sporadically distributed fauna, consisting mainly of long range forms, particularly brachiopods. Such a definition seems to fulfil all the essential requirements of a reef-limestone, but it excludes certain commonly occurring features, such as tufaceous deposits, crinoidal limestones, and limestone breccias. A reef-limestone is not necessarily a highly fossiliferous deposit ; in fact some Carboniferous reefs contain considerable masses of substantially unfossiliferous rock.

The above definition of a reef facies takes no account of the actual mode of origin of the limestone or its relation to the surrounding strata. There is, indeed, much evidence for the view that the Avonian reefs were built up in more than one way. Thus the reef knolls in the C zone of the Clitheroe-Bowland district appear to be discrete accumulations enveloped in shales (Parkinson, 1926, 1935), whereas the Cracoe knolls have been interpreted as erosion features in a once continuous zone of limestone which Hudson (1930, 1932, 1933) has named the Craven Reef Belt.

Neither does the term reef facies imply any particular topography such as knoll topography. A reef-knoll is characteristically an isolated rounded or conical hill made of reef-limestone, but reef-limestones do not necessarily form knolls, or they may, under certain circumstances form knolls of unusual shape (Hudson, 1932).

Hudson has interpreted the reef facies of the Craven Reef Belt as a marginal facies between the Great Scar Limestone (massif facies) to the north and the impure limestones and shales of Pendleside type (basin facies) to the south (1932, 1933). He considers that the position of this reef belt was controlled by the southern edge of a buried Lower Palaeozoic horst and suggests that the " Derbyshire Reef Belts were apparently formed in the same way on the edges of the South Pennine horst ". Cope (1939, p. 65) showed that " the S_2–D_1 beds of the central part of North Derbyshire are distinctly of Great Scar facies. They are relatively unfolded limestones of shallow water type, being in the main thick-bedded poorly fossiliferous light coloured limestones, calcite mudstones, and pseudobreccias ". These are the deposits of massif facies (in Hudson's sense) which can be regarded as having been accumulated upon the South Pennine rigid block. Cope mentions that " the presence of reef-limestones in the extreme north of the area about Castleton, suggests that the edge of the block is being approached in a northerly direction, and that the Carboniferous Limestone beneath the uplands of the Peak may be represented by basin facies ".

Two types of reef deposit have recently been described in the Upper Palaeozoic of North America. One of these, of Mississippian age, is considered by Laudon and Bowsher (1941) to have formed distinct knobs on the sea floor, and is compared with the Lower Viséan reef knolls of the Clitheroe area described recently by the author (1943) in *Proc. Geol. Soc.* and in a forthcoming paper in *Quart. Journ. Geol. Soc.* The other, which forms thick deposits in the Permian of West Texas and New Mexico is described by P. B. King (1942).

These Permian reef masses, which are found in the Guadalupe Mountains region, accumulated on the edge of the Permian Delaware basin where the facies are complex as a result of differential subsidence. King considers (pp. 634–642) that the reefs grew on a sloping bottom on the sites of monoclinal flexures along the margins of the basin. Their thickness is considerable and is much greater than that of either the basin or shelf deposits. Their growth was maintained by continued greater subsidence of the basin than of the adjacent shelf areas. The steeper dips of the reef facies are thus original features. King shows " that during deposition the surfaces of the reefs rose sharply above the floor of the Delaware basin and that their tops stood at great height above it ". He further points out that in the " back reef " area the non-reef (shelf) deposits are nearly horizontal and that " when individual beds change into reef facies they do not rise, but remain nearly flat ". In contrast to the basin deposits the " back reef " deposits seem to have been laid down in shallow water. King postulates (p. 730) that warmer, more agitated water on the margins than in the deep basins would increase precipitation of calcium carbonate and favour food-getting by lime-secreting organisms.

3. THE D_1 LIMESTONES OF ELDON HILL

The boundary of D_1 and the Castleton Limestone is mapped by Shirley and Horsfield as roughly following the line of the Castleton-Sparrowpit road. South-east of the road the two *Cyrtina* (*Davidsonina*) *septosa* bands, which are separated from each other according to these authors by about 100 feet of strata, can be seen in places. The lower band is exposed on the north-western slope of Eldon Hill at the north edge of Eldon Hill quarry which Shirley and Horsfield announce as having been recently opened when they were working in the district. The quarry now extends upwards to somewhere near the higher *C. septosa* band, which is exposed in the quarry at Slitherstones Mine about a quarter of a mile east of Eldon Hill quarry.

The age of the deposits in Eldon Hill quarry is, therefore, according to the mapping of these authors, that of the upper half of the Chee Tor beds of the D_1 zone. The rock is very fossiliferous, the fauna consisting mainly of brachiopods. One day's collecting yielded the following among other species. *Amplexus coralloides* Sowerby, *Dibunophyllum bourtonense* Garwood & Goodyear, *Lithostrotion irregulare* (Phillips), *Brachythyris pinguis?* (Sowerby), *Cyrtina* (*Davidsonina*) *septosa* (Phillips), *Dielasma hastatum* and varieties (Sowerby), *Martinia* cf. *glabra* (Martin), *Productus* (*Avonia*) *youngianus* Davidson, *P.* (*Buxtonia*) *scabriculus* (Martin), *P.* (*Echinoconchus*) *punctatus* (Martin), *P.* (*Gigantella*) cf. *maximus* McCoy, *P.* (*Krotovia*) *aculeatus* (Martin), *P.* (*Overtonia*) *fimbriatus* J. de C. Sowerby, *P.* (*Plicatifera*) *mesolobus* Phillips, *P.* (*P.*) *plicatilis* J. de C. Sowerby, *P.* (*Pustula*) *pustulosus* Phillips, *Pugnax acuminatus* (Martin), *Reticularia* cf. *acutiplicata* George, *Schizophoria resupinata* (Martin), *Spirifer* cf. *striatus* Martin.

This assemblage clearly indicates a reef facies of D_1 age, and the lithology, moreover, is characteristic of a reef-limestone. Eldon Hill as a whole, however, is not a reef knoll. Towards the east and south-east from Eldon Hill quarry the facies change, and the reef facies appears to be completely absent from the D_1 rocks of the Slitherstones Mine quarry on the north slope of the hill. It is interesting to note that Eldon Hill does not exhibit the characteristic abrupt knoll topography, the reef-limestone being confined to the north-western slope, and thus the topography is controlled by the approximately horizontally bedded D_1 limestone of what Hudson calls the massif facies which occupies the summit of the hill. The reef-limestone makes no feature at all, a fact in keeping with the view that its transition to the massif type is a gradual one.

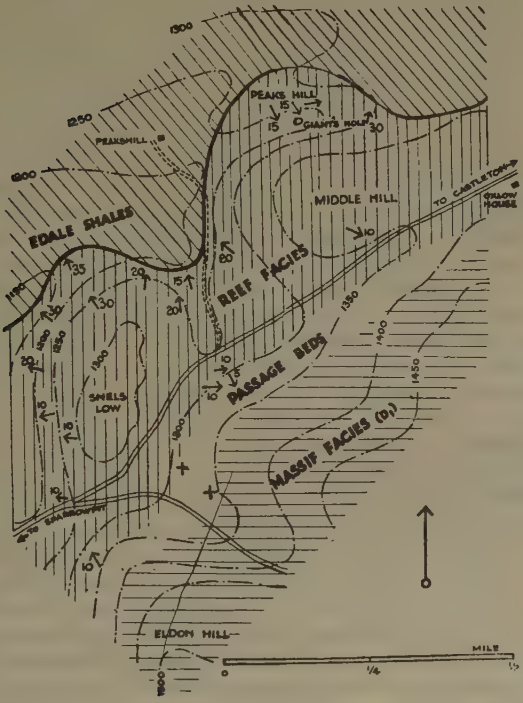
The gradual nature of the transition from reef to massif type is illustrated along the steep slope which runs from Eldon Hill quarry in the direction of Oxlow House. The higher parts of this slope are relatively unfossiliferous D_1 limestones, but lower down the hillside there is a mixed though sparse fauna of reef forms and D_1 corals. The beds in the author's opinion, constitute a passage between the reef facies of Middle Hill and the massif facies on the plateau to the east.

But Shirley and Horsfield have a different view. They state for instance that " in a small quarry immediately above the third milestone from Castleton knoll reef-limestone with goniatites rests on an irregular surface of bedded limestone with *Cyrtina septosa* and *Palaeosmilia murchisoni* ". In this exposure the author found a goniatite (indeterminable), but evidence of irregular contact between the rock containing it and the limestone with corals below was not seen.

Shirley and Horsfield claim that everywhere the transition from D_1 to the reef type is abrupt. The author has invariably found the change in facies to be a gradual one. Thus in the exposure 130 yards south of Oxlow House in which, according to Shirley and Horsfield " breccia dipping at 10 degrees north-west is in contact with horizontal ' spotted limestone' (Chee Tor Limestone)" the exact position of the "contact" was not found. But if the breccia were of D_1 age an abrupt transition would not be expected.

4. THE REEF-LIMESTONE OF PEAKS HILL, MIDDLE HILL, AND SNELSLOW

In the type of fauna and lithology which they display, in the fact that they exhibit quaquaversal dips and to some extent in their topography the knolls of Middle Hill, Peaks Hill, and Snelslow resemble some of the older (C_2) reef knolls of the Clitheroe-Bowland district. The limestones constituting both these groups of knolls are followed unconformably by black shales—Edale Shales in the Castleton district, Worston Shales at Clitheroe—but whereas the reef-limestones of the Clitheroe knolls are separated from each other by argillaceous deposits of the same age as themselves, no such deposits have been found in similar relation to the Castleton limestones. There is, for example, in the depression between Middle Hill and Snelslow no evidence of a facies change, although Shirley and Horsfield show on their map a tongue of D_1 limestone of the massif facies running between the two knolls. These authors state that Snelslow and Middle Hill "are probably stacks of D_1 limestone with a capping



of B_2 reef, much like a wig on a head and the quaquaversal dip is a consequence of this relationship". They also refer to "a small window of D_1 limestone between Middle Hill and Peaks Hill". Careful examination of the ground has convinced the author that all the exposed rock of Peaks Hill, Middle Hill, and Snelslow, both on the hills and in the depressions between them is of reef facies. The brachiopod fauna of these knolls is similar to that in Eldon Hill quarry. Occasional corals, including several species of *Lithostrotion* and a very large *Caninia* resembling *C. juddi* (Thomson), occur sporadically among the much more abundant brachiopod fauna. Jackson (1941, p. 246) records the characteristic D_1 brachiopod *Cyrtina* (*Davidsonina*) *septosa* on the south flank of Middle Hill.

The total thickness of reef-limestone in the area between Eldon Hill and Peaks Hill is very difficult to estimate. The base is not reached, though it may be proved to be not far below the level of the lower *D.* (*C.*) *septosa* band. Its upward extension will now be considered. According to Shirley and Horsfield about 80 feet of Miller's Dale Limestones lie between the Chee Tor beds and the base of D_2. This means there are about 200 feet of D_1 above the lower *C. septosa* band. The development of reef-limestone at Snelslow and Middle Hill almost certainly exceeds 200 feet and thus, unless the beds thicken in passing from the massif to the reef type we might expect the higher beds of these knolls to be of D_2 age. Near the junction with the Edale Shales the highest beds of Middle Hill and Peaks Hill near Giant's Hole are crowded with fossils, notably brachiopods. Some of the shells are whole and well preserved; others are broken, probably by wave action.

Among the fauna collected are *Amplexus* aff. *coralloides* Sowerby, *Lithostrotion junceum* (Fleming), *Syringopora* sp., *Camarotoechia* cf. *pleurodon* (Phillips), *Dielasma* cf. *hastatum* (Sowerby), *Martinia* cf. *glabra* (Martin), *Phricodothyris insolita* George, *Productus* (*Avonia*) *youngianus* Davidson, *P.* (*Buxtonia*) *scabriculus* (Martin), *P.* (*Dictyoclostus*) *antiquatus* Sowerby, *P.* (*D.*) *insculptus* Muir-Wood, *P.* (*D.*) *sulcatus* Sowerby, *P.* (*Echinoconchus*) *elegans* McCoy, *P.* (E.) *punctatus* (Martin), *P.* (*E.*) *subelegans* Thomas, *P.* (*Pustula*) *pustulosus* Phillips, *P.* (*Krotovia*) *spinulosus* (Martin), *P.* (*Plicatifera*) *plicatilis* J. de C. Sowerby, *Schizophoria resupinata* (Martin), *Schizostoma catillus* (Martin), *Goniatites* aff. *crenistria* Phillips, *G. maximus* Bisat.

The goniatites indicate a high horizon in B_2. The brachiopod fauna includes a number of species also found in Eldon Hill quarry and might belong to either D_1 or D_2. The uppermost beds of Middle Hill and Peaks Hill can nevertheless be referred to D_2 mainly on the evidence of the occurrence in them of *Palaeosmilia regia* (Phillips), (Jackson, 1927), a coral not known below D_2.

5. THE TREAK CLIFF—CAVE DALE AREA

In discussing the evidence for unconformity below the Castleton reef-limestone Shirley and Horsfield refer particularly to the crag on the east side and near the top of the small gorge-like valley north of the Blue John

Cavern. They point out that the contact between the Castleton Limestone and the D_1 limestone " is very irregular, going down through the crag in a steep northerly direction ".

A break in the succession at this point is clearly indicated and the actual contact shows that the higher beds were deposited to a depth of several feet against a steeply inclined irregular surface. Immediately above the junction the limestone is more broken and considerably more fossiliferous than it is below it. The type of fauna, however, is similar on both sides of the junction, consisting primarily of brachiopods of reef facies. There seems no reliable means of estimating the magnitude of the break in the sequence at this point other than by a comparison of the faunas on each side of it. Field evidence does not, in the author's opinion, indicate that it is of major significance. The brachiopod fauna immediately above the break does not suggest a higher level than D_2.

Sixty yards up-stream from the above exposure Shirley and Horsfield record the D_1 corals *Palaeosmilia murchisoni* and *Dibunophyllam bourtonense*. According to the same authors " the contact between the reef limestone and bedded limestone can also be seen at the junction of a small side valley with the Winnats 200 yards east of Winnats Head Farm. The rather unfossiliferous bedded limestone dips south-west at 7 degrees whereas the reef limestone dips in an easterly direction ". The author has been unable to find any actual contact between the two types of limestone in this locality ; in fact he has been unable to detect any sudden change in the character of the rock or its fossils at this point, the limestone being, in his view, either of reef facies or of a type intermediate between reef and massif facies as developed locally in D_1.

The relations are also stated to be clear at the head of Cow Low Nick. The dip of the reef-limestone here increases from 20° N.E. at the head of the gully to about 40° in the gully. Limestones exposed near by which dip at 15° S.E. are stated to be bedded D_1 limestones as distinct from reef-limestones. Although not remarkably fossiliferous at this point these bedded rocks contain reef brachiopods, and cannot be regarded as essentially different from deposits elsewhere recognized as reef-limestones by Shirley and Horsfield.

South-south-east of Castleton a few isolated patches of reef-limestone are mapped by Shirley and Horsfield as unconformable on D_2. A small exposure 200 yards west of Bird Mine contains 6 feet of brachiopod reef-limestone which is shown to dip at 20° N. and to be discordant to the *Lonsdaleia duplicata* band here stated to dip at 4° S.E. The reef-limestone at this point is said to be " of small extent and is evidently only a relic, but its importance lies in the fact that it rests on limestone of proved D_2 age ". The author has examined this exposure and confirms it to be a reef-limestone. He has failed, however, to find any exposure of different limestone underlying it.

About 200 yards north-north-west of the above exposure is another which is quite as unmistakably a reef-limestone, but is not mapped as such by Shirley and Horsfield. This exposure contains *Lonsdaleia duplicata* (Martin) and is correctly referred to D_2 by the above authors. The brachiopods include *Martinia* cf. *glabra* (Martin), *Phricodothyris* sp., and a number of Productids comprising *Buxtonia scabricula* (Martin), *Dictyoclastus* sp., *Eomarginifera* sp., and *Krotovia spinulosa* Martin.

The extent of this reef-limestone, which appears to be a local facies in D_2 and its relation to the upper B_2 (D_2 ?) beds of Treak Cliff and Peaks Hill are matters which are receiving further attention.

6. The Supposed Mid-Carboniferous Coast Line

In support of their contention that the reef-limestone is banked against cliffs of at least 550 feet Shirley and Horsfield state that its dip is always away from the surface of the nearest bedded limestone. This, they say, " is a consequence not of tectonic movement, but of the conditions of deposition. On the faces of the steep slopes the dips are of the order of 30°–40°, and in all probability reproduce very nearly the angle of rest under water of the scree material of which they are composed. On approaching the more or less flat surface at the top of the slopes the dips in many cases tend to flatten." Broadly speaking the cliffs are regarded as representing the coast line of the period.

If this were the true explanation we should expect the reef-limestone to consist for the most part, if not entirely, of scree material derived from the supposed cliffs of D_1 limestone. But as a matter of fact most of the Castleton Limestone is normal reef-limestone of D_1 age, usually considerably more fossiliferous than the D_1 limestone of massif type which contains a sparse fauna with few individuals. It seems to have in great part grown in its present position. It is brecciated locally, but not to anything like the extent which would be expected from a scree deposit on a grand scale.

If the Castleton Limestone accumulated against an old shore line of steep cliffs with bays and promontories we should expect it to exhibit the normal features of an overlapping deposit, i.e. original horizontal bedding with probably a conglomeratic base. But the conditions of accumulation were not of this type ; the dips tend to increase outwards from the main outcrop of D_1, and downwards as at Treak Cliff and Cow Low Nick towards the lower ground. This arrangement of dips can be accounted for on the assumption that the deposits were formed on the slope of a reef. This point is further considered on p. 129.

Having formulated their theory of vertical unconformity Shirley and Horsfield elaborate it by attributing some of the more prominent present-day features of the topography to mid-Carboniferous and pre-reef limestone erosion. Thus they state that " Cavedale and the Winnats are, in part at least, mid-Carboniferous features ". It is not within the scope of the present paper to discuss the origin of these dry gorges, but there are other explanations at least as satisfactory as that postulated by Shirley and Horsfield. If these valleys are in fact mid-Carboniferous features, they are more likely, in the author's view to have been initiated after the deposition of the reef-limestone than before it, in other words, between the deposition of the Nun Low beds and the Edale Shales.

The phenomena displayed at Windy Knoll are instanced by Shirley and Horsfield as providing further evidence of a coast line. Here the limestone breccia (which contains the well known deposit of elaterite) is interpreted as a series of "Neptunean dykes in a promontory of D_1 limestone against both sides of which were banked breccia or knoll reef limestone". It is difficult to accept this interpretation of the breccia. If the views expressed in the present paper are correct there is no need to postulate Neptunean dykes to account for the position of the breccia at this point. There are, however, vertical fissures in the limestone of Windy Knoll filled with Edale Shales. If we accept Shirley and Horsfield's view it would therefore appear that Neptunean dykes of two distinct ages, represented by two distinct unconformities, are present at the same spot, a rather remarkable coincidence.

7. THE RELATIONSHIP OF THE REEF-LIMESTONE TO THE LIMESTONE OF THE MASSIF

It has been shown above that the lower part of the Castleton Limestone is a reef facies of D_1 age lying on the north-western edge of the limestone plateau. South-eastwards the facies changes to the Chee Tor Limestone type which Cobb, following Hudson, has referred to as the massif facies. The present outcrop of reef-limestone is a narrow and irregular one since it dips to the north and west under the Edale Shales which are unconformable on it. The passage from reef facies to massif facies is in the light of the author's field observations, a gradual one, and in keeping with this gradual change there are no sudden changes in the topography. The reef-limestone usually dips at higher angles than does the limestone of the massif, which is for the most part lying approximately horizontally.

In general the farther the site is from the main mass of limestone the steeper is the dip of the reef-limestone, as pointed out by Shirley and Horsfield. This dip is usually outwards from the massif, and as also pointed out by them it must be regarded largely as original. The quaquaversal dips of Snelslow and Middle Hill show a departure from this generalization, but the magnitude of the dip where it points towards the massif is usually small, and probably partly a consequence of tilting during subsequent earth movement which has similarly disturbed the horizontality of the main limestone mass.

The increasing angle of dip as the distance from the massif increases suggests deposition on a slope, and we can visualize a clear shallow sea with quiet sedimentation in which the D_1 beds of massif facies were accumulating, and between this and the deeper and probably more open water to the north and west a submarine slope or reef providing a favourable site for brachiopods. There would appear to be a fairly close comparison between the type of reef here postulated and that discussed by King (1942) in the Permian of West Texas and New Mexico.

In contrast to the reef knolls of Clitheroe and Bowland which are discrete accumulations probably in some cases several miles in length, yet never exceeding much more than half a mile in width, the Castleton limestones do not form individual reefs. Snelslow, Middle Hill, Peaks Hill, Windy Knoll, Treak Cliff, and the cliffs of the Winnats and Cave Dale can all be regarded as part of the same reef. Under conditions such as are here postulated, limestone-breccias and conglomerates resembling those along the ridge from Oxlow House to Windy Knoll might be expected to occur locally.

Probably about the end of D_1 time an uplift occurred resulting in erosion of the reef-limestone in places. The succeeding deposits of upper B_2 (D_2 ?) age, along the north and west margin of the area under consideration are also reef-limestones and the irregular contact between them can be seen in the crag north of the Blue John Cavern. The exact delimitation of the beds above and below this break will form the subject of further work, as will the relationship of the Nun Low beds to the other deposits in the district.

8. PROVISIONAL CONCLUSIONS

Reef-limestones are shown to occur in rocks of D_1 (lower B_2 ?), upper B_2 (D_2 ?) and D_2 age in the Castleton district. This agrees with Jackson's conclusions, but conflicts with the views of Shirley and Horsfield, who consider the Castleton reef limestones to be unconformable on D_1 and D_2, and to be deposited against a shore line of mid-Carboniferous age. The author's work supports Hudson's hypothesis that the Castleton Limestone formed reef-like deposits along the margin of the Derbyshire massif. Further work is necessary to establish the details of the succession and the present conclusions must be regarded as tentative.

The author has had the benefit of discussing this problem and examining many of the exposures with Dr. A. Lamont to whom he expresses thanks. He also wishes to thank Professor L. J. Wills, who has kindly read and criticized the manuscript of this paper.

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Notes on Certain Upper Devonian Brachiopods figured by Whidborne

By F. R. C. Reed

(*Concluded from p. 106*)

Genus : ATHYRIS McCoy

Athyris concentrica von Buch ?

Dehée (1929, p. 26) has pointed out that there has been much confusion and difficulty in distinguishing *A. concentrica* from *A.* (*Cleiothyridina*) *roissyi*, and Weller (1914, p. 473) referred to Davidson's too broad interpretation of that species. One impression [H. 251] from Poleshill which Whidborne figured (1897, pl. xviii, fig. 3) under the latter name does not possess the characteristic spinosity of *A.* (*Cl.*) *roissyi*, but agrees instead with *A. concentrica* which is a typical Devonian species characteristic of the Upper Devonian, as Dehée remarks who figures examples of it (1929, p. 26, pl. iv, figs. 4–6) from Etroeungt.

The other figured specimens in the Sedgwick Museum which Whidborne (1897, pl. xvii, figs. 14, 15, pl. xviii, fig. 5) attributed to *Athyris roissyi* l'Éveille, apparently belong to other species or genera, but nearly all are in so unsatisfactory a state of preservation that their determination is a matter of greater uncertainty.

Athyris cf. *lens* (Winchell)

The complete internal cast of a subcircular biconvex shell [H. 247] from Ashford Strand which Whidborne figured (1897, p. 147, pl. xvii, fig. 11 *non* 12) as *Athyris* (*Seminula*) *oblonga* (Sowerby) together with the impression of part of the external surface of the same shell (fig. 11*a*) cannot be referred to Sowerby's species, for it differs in shape and in the absence of a median septum in the brachial valve. Whidborne (*op. cit.*) gave a description of the species which was based largely as he stated on this specimen, but it is not applicable to Sowerby's species and is not entirely complete or correct even if limited to this specimen, for he did not mention that the dental plates in the pedicle-valve are gently arched and help to bound the oval muscle-scar which is about one-third the length of the valve and consists of a pair of subscrescentic diductors enclosing a pair of narrow parallel adductors. The shell also should be described as suborbicular and subglobose, and there is no marginal fold or sinus. The brachial valve is somewhat broken at the umbo, but has a pair of very short stout crura ; the muscle-scars are indistinct and there is no median septum. The impression of the external surface (Fig. 11*a*) shows a smooth shell with two or three thin wide lamellose growth-ridges near the anterior margin. The internal characters as well as its external shape and smooth surface suggest a comparison with *A. lens* (Winchell) as described by Ehlers and Kline (1934, p. 165, pl. iv, figs. 7–11) from the Devonian of Michigan, and also with *A. spiriferoides*

Eaton (Hall and Clarke, 1894, pl. xlv, figs. 11–25) of the Hamilton Group in America.

Athyris (*Cleiothyridina*) cf. *devonica* Raymond

The crushed and imperfect specimen [H. 252] from Pilton which Whidborne (1897, pl. xviii, fig. 5) attributed amongst others to *Athyris roissyi* has none of the characteristic ornamentation of that species and may be better compared with *A.* (*Cleiothyridina*) *devonica* Raymond (1909, p. 143, pl. iii, figs. 16, 17, pl. iv, figs. 1–11) from the Upper Devonian of Montana, but no spiniform extensions of the free margins of the concentric lamellae can be detected in this British specimen, nor are they clearly shown in Raymond's figures of complete examples of the type. As Raymond remarks this species is very different from the typical *A. roissyi* from the Carboniferous.

Genus : CRURITHYRIS George

Crurithyris unguiculus (Sowerby)

The specimens [H. 261] which Whidborne (1897, pl 157, pl. xix, figs. 5–7) described as *Spirifera* (*Martinia* ?) *urei* Fleming are placed by George (1931, p. 52, pl. iii, figs. 3–6) in his genus *Crurithyris* and referred to Sowerby's species *Atrypa unguiculus* (J. de C. Sowerby 1840, pl. 54, fig. 8). Rigaux records (1908, p. 20) this species from Ferques. Peetz (1901, p. 112) put *Spirifer urei* Fleming in the genus *Reticularia*, but Paeckelmann (1931, p. 296) retained it with a query in *Martinia*. *Ambocoelia gregaria* Hall var. *asiatica* Reed (1922, p. 112, pl. xvi, figs. 15–20) from the Upper Devonian of the Pamirs appears to be closely related.

Crurithyris unguiculus (Sowerby) ? var. *bilobata* nov.

Though George did not separate it, Whidborne's specimen [H. 260] fig. 6 on pl. xix from Barnstaple seems to be at least varietally distinct from *C. unguiculus*, as indeed Whidborne thought, owing to its possession of " an unusually small beak and a very deep angular sinus ". In this it agrees much more closely with one of Phillips' figures (1841, pl. 28, fig. 119*a*, non. cet.) of *Spirifera unguiculus* than with Sowerby's type of the species, and it was apparently described by Phillips (1841, p. 69) as a variety. The strong bilobation of the valve, the shorter hinge-line, as well as the angularity, continuity and increase in width of the sinus from the beak to the margin are distinguishing features. The surface of the internal cast, which shows clearly the median septum and teeth, is densely covered with small granules and punctae which are seen to be clearly arranged in concentric lines on parts of the lateral lobes.

The brachiopod from the Frasnian of Aachen which Klähn (1912, p. 26, t. 2, fig. 6) named *Ambocoelia walheimensis* and considered it to be allied to *A. umbonata* Hall of the Hamilton formation has a somewhat similar pedicle-valve, and so has *A. umbonata* var. *gregaria* Hall, as figured by Prosser (1912, p. 539, pl. xxxi, figs. 6–9), but it possesses a higher umbo and longer hinge-line than this supposed variety of *C. unguiculus* which we may call *bilobata*. Peetz (1901, p. 133, t.v., figs. 2*a*, *b*) figured a specimen from the Devonian of West Siberia as *Athyris cora* Hall (1867, p. 291, pl. xlvii, figs. 1–7) of the Hamilton formation which bears a great resemblance to this Barnstaple specimen, but the American type is more transverse and the sulcus less deep and broad. Some specimens attributed to *Spirifer curvatus* (Schloth.) such as the one figured by Davidson as a variety from Woolborough (1864, pl. ix, fig. 22) appear to be much like it, but the umbo rises higher above the hinge-line.

Genus : YUNNANELLA Grabau

Yunnanella partridgiae (Whidborne) (pars)

The first figured specimen [H. 265] of *Rhynchonella* (*Camarotoechia*) *partridgiae* Whidborne (1897, p. 161, pl. xix, fig. 12) is from Pilton and consists of the internal cast of a small brachial valve, but neither the figure nor the description are wholly correct or complete, and the two other figured specimens figured by him under the same specific name are distinct and both are of pedicle-valves.

The small brachial valve (fig. 12) shows by its internal characters that it can hardly be referred to *Camarotoechia.* For the hinge-plate is transversely crescentic and is not divided by any median slit as Whidborne's figure incorrectly represents, but has a median oval perforation or pit near its posterior (umbonal) edge with a short transverse groove at right angles to it on each side ; the anterior edge of the hinge-plate is much thickened, and its face is excavated by a pair of deep conical pits, one on each side of a small median spondylium from which there is a thin median septum extending about three-fourths the length of the valve ; the posterior ends of the small divergent plates bounding the spondylium appear to rise into small sharp prominences on joining the hinge-plate ; the bases of the crura are seen on the anterior lateral angles of the hinge-plate ; the umbo is low and small, and the dental sockets are crenulated on their outer face as Whidborne noticed. There are no distinct traces of muscle-scars. The ribs are only prominent, coarse and angular in the anterior third of the valve ; elsewhere they are represented on the posterior two-thirds of the valve by pairs of narrow linear costellae which unite anteriorly to form the ribs ; four of the ribs form the median fold which is slightly elevated in front above the lateral lobes but not raised above them posteriorly ; a strong median septum dying out at two-thirds the length of the valve lies along the median sulcus on the fold making the ribs form two pairs. The lateral lobes carry six similar angular coarse ribs, but only in their anterior third. The shell is punctate.

Dimensions.

Length . .	13.0 mm.
Width . .	17.0 mm.

Remarks.—The peculiar development of the ribs is unlike any found in *Camarotoechia* and resembles *Yunnanella* Grabau (1931, p. 141), being especially like *Y. ericsoni* Grabau (1931, p. 154, pl. xii, fig. 9, pl. xiii, figs. 4, 5) from the Upper Devonian of Hunan. The allied species *Rhynchonella schnuri* (d'Archiac and de Verneuil, 1840, p. 281, pl. iii, figs. 2*a–d*) from the European Devonian and from the Northern Shan States (Reed, 1908, p. 91, pl. xiv, figs. 16, 16*a*) belongs to the same genus, but it has more numerous radial costallae on the posterior part of the shell. The internal characters of *Yunnanella* have not been described, but our specimen differs from *Camarotoechia* internally in the hinge plate not being divided as well as in other details. Nalivkin's specimens, from Turkestan, which he referred to Whidborne's species (1930, p. 67, t.v, figs. 14, 20) appear to be entirely different. *Y. hanburgi* which occurs in China in the Devonian (Davidson, 1853, p. 356, pl. xv, figs. 10, 11 ; Grabau, 1931, p. 157, pl. xvi, figs. 1–3, text-fig. 13) has a much higher fold on the brachial valve, but otherwise is allied in external characters to Whidborne's shell, for the flattened appearance of the latter may be partly due to crushing. The variety *lata* described by Grabau (1931, p. 162, pl. xvi, figs. 4–8) more nearly approaches it in this respect. It may be observed that Grabau puts this species in a subgenus *Yunnanellina.*

Genus : CAMAROTOECHIA Hall and Clarke

Camarotoechia c.f. *sappho* (Hall)

The second specimen [H. 266] from Pilton figured by Whidborne (pl. xix, fig. 13) as *Rhynchonella* (*Camarotoechia*) *partridgiae* is quite distinct from the brachial valve above described. It consists of the internal cast of a large transversely subelliptical pedicle-valve, and Whidborne did not describe its characters correctly, for he combined it with the third specimen (see below) which he figured as belonging to the same species. The sinus in the present specimen has a flat floor holding three ribs and deepens rapidly to the front ; the lateral lobes have 5–6 much stronger angular ribs curving back slightly, continuous from the umbo to the margin, but increasing in height towards their ends so that longitudinally they have a concave upward curve ; each has a narrow groove along the middle third of the length of its crest, but this may only indicate an internal thickening of the crest of the ribs. The thin dental plates diverge from the umbo at about 60° and merge distally into the concentric ridge which encloses the broadly suboval muscle-scar which extends about half the length of the valve. The umbonal cavity is not separated off from the muscle-scar as is usual in *Camarotoechia*, and as it is in the third specimen figured by Whidborne (pl. xix, fig. 14) from Roborough under the same specific name (see below).

Dimensions.	
Length . .	14 mm.
Width . .	21 mm.

Remarks.—In shape and costal characters it much resembles *Camarotoechia sappho* (Hall) (1867, p. 340, pl. 54, figs. 33–43 ; Hall and Clarke, 1894, pl. lvii, fig. 11) from the Hamilton formation of New York and Ohio, but the grooving of the ribs in the internal cast is peculiar, and the muscle-area is of unusual shape.

Mansuy (1912, p. 81, pl. xv, figs. 6*a–h*) compares his Yunnan species *Rh.* (*Cam.*) *convexa* with *C. sappho*, and his description is repeated by

Grabau (1931, p. 105, pl. i, figs. 13*a*, *b*), but the figures do not seem to indicate allied species. It is not clear which of Whidborne's specimens of *C. partridgiae* (or possibly all of them) Paeckelmann (1913, p. 268) put in the genus *Terebratuloidea*, or for what reason he did so.

Camarotoechia cf. *congregata* Hall

The third figured specimen [H. 267] referred by Whidborne to his species *Rhynchonella* (*Camarotoechia*) *partridgiae* (1897, pl. xix, fig. 14) is the internal cast of a pedicle-valve from Roborough possessing the usual characters of the genus *Camarotoechia*, and the slightly upturned ends of the ribs as in the Pilton specimen which has been here compared with *C. sappho*. But the present shell has a rounded subtriangular shape, being much less transverse than that of the specimen [H. 266] from Pilton compared with that species and above described, and the muscle-scar is more elongated in shape widening anteriorly and having longer thicker dental plates bounding it posteriorly and diverging at an angle of only about 30° ; the umbonal cavity is also distinctly marked off. There are 3 ribs in the shallow flat sinus and 5–6 larger ones on each lateral lobe with a trace of a groove along part of the crest of each rib.

The variable species *C. letiensis* Gosselet as figured by Dehée from Etroeungt (1929, p. 29, pl. iv, figs. 8–12) and by Frech (1916, p. 214, t. i, figs. 5, 6) from the Taurus shows many points of resemblance to this specimen, but there is no grooving of the ribs which makes us hesitate to refer it to the same species. But we may best compare *C. congregata* var. *parkheadensis* Clarke and Swartz (1913, 575, pl. liii, figs. 11–16) from the Upper Devonian of Maryland.

Dimensions.

Length . . .	16 mm.
Width . .	18 mm.

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Restoration of the Original Form of Distorted Specimens

By Philip Lake

(PLATE VII)

MANY fossils in the older rocks have been distorted by pressure, and if only one specimen is available it is often difficult to be sure of its original proportions. Sometimes, however, there is a specimen which not only furnishes sufficient data for the determination of its original form, but can be made to yield a photograph in which the distortion is corrected. In his paper on " Slaty Cleavage " Harker[1] showed how, in such cases, the distortion can be determined, and he referred to an earlier paper by Dufet[2] in which the same principle is used, though in a different way. So far as I know the method of correcting the distortion photographically has not previously been employed.

The specimen with which I deal belongs to the species that Salter called *Ogygia scutatrix*, but it should probably be referred to the genus *Niobe*. It lies in the bedding-plane and has evidently been much flattened. As it lay upon the mud the head was torn apart and now lies obliquely to the thorax. It was probably by the same disturbance that the pleurae of the left side were pressed together, and those on the right side were opened out and the mud squeezed between them. All this must have happened while the mud was still soft.

The specimen is now very flat, but the faceting of the pleurae indicates that it was originally much more convex. The regularity of the flattening and the fact that the rock splits so cleanly along the bedding are sufficient to show that the pressure which caused the flattening was, exactly or approximately, vertical to the bedding. Probably it was due to the weight of overlying sediment.

The specimen does not enable us to determine the amount of the flattening ; but, apart from this, there is distortion in the plane of bedding, and the nature and amount of this can be determined with considerable accuracy. It will be noticed that the axial rings of the tail are still at right angles to the median line, as they were before distortion. But in the head, which lies obliquely to the tail, the neck-ring is not at right angles to the median line of the glabella, as it must originally have been. It is this difference between the head and the tail that enables us to determine the original form, exclusive of the effects of flattening.

To the naked eye the slab on which the specimen lies is very fine-grained and uniform. Under the microscope a section at right angles to the surface shows thin quartzose laminae interbedded with still finer material, but even the quartzose laminae are very fine-grained. The lamination is very slightly undulating, but there is no crumpling.

Since the rock is so uniform and has throughout been subjected to the same conditions, we may reasonably suppose that it has everywhere yielded uniformly to the pressures exerted upon it. All straight lines in the rock which were originally parallel to one another bore the same relation to those pressures, and must accordingly have been affected in the same way; they may have changed their direction, but they must have changed together, and must still remain straight and parallel. If they have altered in length they must have altered in the same ratio; but not necessarily in the same ratio as lines in some other direction, which would be differently related to the pressures.

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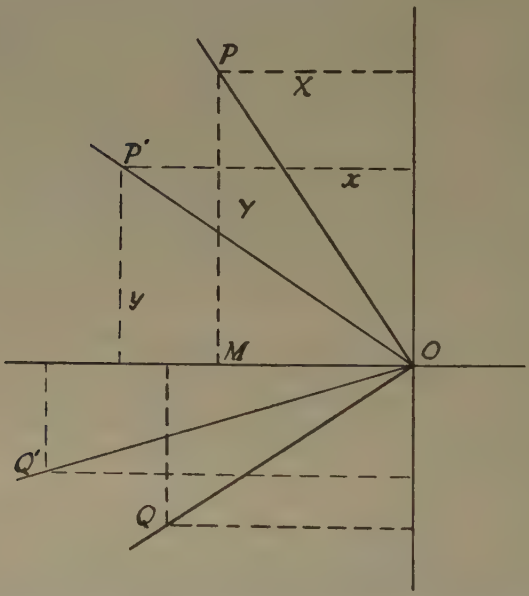
[1] *Rep. Brit. Assoc.* for 1885, p. 827.

[2] *Ann. de l'Ecole Norm. Sup.*, sér. 2, t. iv, 183 (1875). Owing to the circumstances of the present time I have been unable to see this paper myself.

These are the characteristics of what is called homogeneous strain. In such strains there are always three directions, and generally only three, which were at right angles before distortion and still remain at right angles after distortion. In this particular example the three directions are (*a*) vertical to the bedding, (*b*) parallel to the median line of the tail, (*c*) parallel to the axial rings of the tail. It is only with the last two that we are concerned—the specimen is practically flat, and we attempt to restore its form after the flattening but before the subsequent distortion.



TEXT-FIGURE.—In this diagram *a* is taken as $\frac{3}{2}$ and *b* as $\frac{2}{3}$.

In the accompanying text-figure the vertical line represents the direction of the median line of the tail, the horizontal line represents the direction of the axial rings. These were at right angles before distortion, and they remain at right angles after distortion. We therefore take these lines as the axes of co-ordinates and fix the position of any point, either before or after distortion, by its perpendicular distance from these two axes. Through O, the intersection of these axes, we draw two lines at right angles to each other, but oblique to the axes. These may be taken to represent the median and transverse lines of a head, before distortion, which lay oblique to the tail.

On the median line of this head take a point P, which is at a distance X from the vertical axis and a distance Y from the horizontal axis. By the distortion all lines parallel to the horizontal axis are altered in length in the same ratio, i.e. their lengths are multiplied by some constant a; all lines parallel to the vertical axis are multiplied by some other constant b. Therefore, after the distortion, the distances of the selected point P from the axes have become aX and bY, and the point P has moved to P', which is at a distance x, $= aX$, from the vertical axis, and a distance y, $= bY$, from the horizontal axis.

For brevity we denote the angle POM by A and the angle $P'OM$ by α; $\frac{Y}{X} = \tan A$, $\frac{y}{x} = \tan \alpha$. Therefore $\tan \alpha = \frac{y}{x} = \frac{bY}{aX} = \frac{b}{a} \tan A$.

Similarly a point Q on the transverse line of the head will be moved by the distortion to Q', and if we denote the angle QOM by B and the angle $Q'OM$ by β, we shall have $\tan \beta = \frac{b}{a} \tan B$.

Therefore $\tan \alpha \tan \beta = \frac{b^2}{a^2} \tan A \tan B$. Since the angles A and B are complementary $\tan A \tan B = 1$; and consequently we have $\tan \alpha \tan \beta = \frac{b^2}{a^2}$.

The angles α and β can be measured on the specimen and thus the ratio of b to a is determined. This much is certain, and it is sufficient to fix the original proportions of the specimen, but not its size. We can, however, proceed further.

By the pressure which flattened the specimen the material of the rock was closely compacted. A thin section at right angles to the bedding indicates that the packing was due entirely, or almost entirely, to the vertical pressure, for there is no disturbance of the laminae which make up the rock, such as there would have been if the packing were not complete before the lateral forces which distorted the specimen came into action. We may conclude, therefore, that the distortion of the specimen in the bedding-plane cannot have been accompanied by any perceptible change of volume, or of the area occupied by the specimen or by any part of it.

In that case we must have $XY = xy = aX \cdot bY$, and therefore $ab = 1$; or a and b are reciprocals. And since $\frac{b}{a} = \sqrt{\tan \alpha \tan \beta}$, the final results are $b = \sqrt[4]{\tan \alpha \tan \beta}$ and $a = \frac{1}{\sqrt[4]{\tan \alpha \tan \beta}}$.

The measurement of the angles α and β can be made most accurately on a direct photograph of the specimen. In the specimen with which we are dealing the median line of the tail is easily determined, and this corresponds with the vertical axis of the diagram; the horizontal axis is at right angles to this. The transverse line of the head is obtained by joining the anterior ends of the two eyes. For the median line of the head we draw another line parallel to this but farther back; by bisecting the parts of these two lines which lie between the axial furrows we fix two median points on the glabella and a straight line joining these two points is the median line of the head. The angle between this line and the horizontal axis is α; the angle between the transverse line of the head and the horizontal axis is β.

According to my measurements $\alpha = 54°$, $\beta = 13\frac{1}{2}°$. This gives—

$$\tan \alpha \tan \beta = 0{\cdot}3306$$

$$\frac{b}{a} = \sqrt{0{\cdot}3306} = 0{\cdot}575$$

$$b = \sqrt{0{\cdot}575} = 0{\cdot}758$$

$$a = \frac{1}{b} = 1{\cdot}319$$

In the preliminary discussion we started with an undistorted head and considered the changes that would take place if all horizontal distances were multiplied by a, so that X becomes aX, $= x$, and all vertical distances were multiplied by b, Y becoming bY, $= y$. The actual problem is the converse of this. We have a distorted head and wish to find its form before distortion. In effect, we are given x and y and have to find X and Y. If $x = aX$ it follows that $X = \frac{x}{a}$ or, because b is the reciprocal of a, $X = bx$. Similarly $Y = ay$.

Therefore, to restore the original form we have to multiply all horizontal distances in the distorted specimen by 0·758, and all vertical distances by 1·319. This may be done, simply enough, by the ordinary methods of the draughtsman, but the process is rather tedious. An equally good result can be obtained photographically with much less labour.

Photographic Method

The process here described is carried out in three stages. In order to test the accuracy of the result a square enclosing the specimen was drawn upon the slab, with one side of the square parallel to the median line of the tail. The middle points of the top and bottom sides were marked by short cross-lines. If the restoration is correct this square will be represented by a rectangle with its sides in the proportion 1·319 : 0·758, or 1 : 0·575, the longer side being parallel to the median line of the tail. Moreover, the cross-lines will still be at the middle points of the sides.

Stage I

A photograph of the specimen is taken in the usual way, with the axial line of the camera lens at right angles to the slab and directed to the middle point of the square (Pl. VII, fig. 1). For convenience of reference this will be called Print I.

If this print is set up with the median line of the tail vertical, and its figure is projected by horizontal rays making an angle of 35° 6′ with its surface and these rays are received upon a vertical plane at right angles to the rays, the square will be represented in the projection by a rectangle. The vertical sides of the rectangle will be of the same length as those of the square, the horizontal sides will be equal to that length multiplied by the sine of 35° 6′, i.e. by 0·575. The cross-lines will be at the middle points of the sides of the rectangle. The projected figure will, accordingly, have the same proportions as the specimen had before it was distorted.

Stage II

An approximation to the projected figure can be obtained photographically by setting up a camera with its back vertical and the axial line of its lens pointing along the rays to the centre of the square. But, because one of the vertical sides of the square is nearer to the lens than the other, the square will not be represented by a rectangle, but by a trapezoid with its vertical sides parallel and the upper and lower sides converging to the horizon of the lens. Moreover, the cross-lines of these converging sides will not be at their middle points. The farther away the camera is set the more nearly will the trapezoid approach to a rectangle and the closer will be the cross-lines to the middle points of the converging sides.

In theory it is always possible to correct the convergence, but in practice there may be difficulties unless a long-focus lens has been used. My lens was a telephoto with an equivalent focus nominally 11 inches, actually 11·64 inches. In order that the definition should be sufficiently sharp throughout the lens was stopped down to f/32. Print II (Pl. VII, fig. 2) was made from the negative obtained, and this completes Stage II.

Stage III

The next step is to take a photograph of this print, preferably with a short-focus lens—mine had a focal length of 50 mm., or rather less than 2 inches. In taking this photograph both the print and the swing-back of the camera will have to be inclined, and it must be possible to slide the camera to and from the object without disturbing the focus to which it has been set, or the direction of its optic axis. The camera that I used was mounted on stout vertical rods along which it could slide. It could be clamped at any height and then a slow-motion screw allowed precise adjustment. The lens pointed downwards and the object to be photographed was placed on a horizontal table below.

The camera is set for reproduction the same size, and this focus is not to be altered. Print II is placed upon this table, but is so inclined that the midvertical and the two vertical sides of the trapezoid will give images of the same length as the mid-vertical of the print itself—the short side of the trapezoid must be nearest to the lens. To facilitate the adjustment the print was mounted on a flat wooden slab and this was hinged to another similar slab. Hinges of gummed paper are sufficient, but care must be taken that the line of the hinges is parallel to the vertical sides of the trapezoid in the print, the longer side being nearest to the hinge. If the method were to be used frequently it would be well to have properly hinged boards with an arc to measure the angle.

The swing-back of the camera should be set at the same angle as the print, but sloping in the opposite direction. The camera is then slid into position so that the mid-vertical of the trapezoid is in focus on the screen. If the inclinations of the print and swing-back are correct the image of the square upon the focusing-screen will be a rectangle with the same proportions as the projection, and the image of the specimen within this rectangle will have the same proportions as the specimen itself before distortion. The cross-lines will be at the middle points of the sides of the rectangle. The photograph will be in focus throughout, even at the full aperture of the lens, but, to allow for small errors in setting, it may be well to use a smaller stop.

The proof of the correctness of the method is based on the usual equation $\frac{1}{d} + \frac{1}{d^1} = \frac{1}{f}$, in which d is the distance of the object from the optical centre of the lens, d^1 the distance of its image, and f the focal length of the lens. The equation is only an approximation, but within the small angle to which our photographs were limited it is sufficiently exact for our purpose. By comparing the rectangle in Pl. VII, fig. 3, with the square in fig. 1 of the same plate, the reader can judge for himself how nearly the former approaches the desired result.

The proof is too long and tedious to be given here, but the practical question is to determine the angle at which the print and swing-back should be inclined, and this is comparatively simple.

The most obvious method is to measure on Print II each of the verticals of the trapezoid, the mid-vertical and the two parallel sides. On the focusing-screen each of these lines is to be equal in length to the mid-vertical in the print. The camera must, in fact, multiply each length by some factor k, which for the shorter side is greater than one, for the mid-vertical one, and for the longer side less than one. If we call the focal length of the lens f, the required distance of the line from the optical centre of the lens will in each case be $\frac{k+1}{k}f$. Having found the distance d_1 for the short side and d_2 for the long side, the print must be tilted so that the short side is nearer to the lens than the long side by $d_2 - d_1$. The difference will very likely be no more than a few hundredths of an inch, which would require great accuracy of adjustment. But if the print is mounted in the way that I have described, upon a slab much wider than the trapezoid, the difficulty is reduced. If the slab, which should be parallel-sided, is ten times as wide as the trapezoid the difference for its two edges will be tenths of an inch instead of hundredths, and will accordingly be much more manageable. The swing-back of the camera is to be tilted at the same angle but in the opposite direction. It is sure to be much wider, and the difference for its edges may easily be an inch or two. This, in fact, is one of the difficulties that is likely to arise in practice. The swing-back may not allow the necessary tilt.

If during Stage II of the process the distance between the negative and the optical centre of the lens has been determined, the angle of tilt for Stage III can be found by a better and less cumbrous method. The optical centre should be determined by any of the usual methods, and this is especially important if a telephoto lens is used, for in such lenses the optical centre may be several inches in front of the lens itself.

Suppose that in Stage II θ is the angle that the optic axis of the lens makes with the surface of Print I and d^1 the distance between the negative and the optical centre of the lens, and that in Stage III f is the focal length of the lens used and ϕ the angle of tilt required in this stage, then—

$$\sin \phi = \frac{f}{d^1 \tan \theta}$$

This tilt is not the angle with the optic axis of the lens but with a plane at right angles to that axis. I give it in this form because in practice it is the most convenient. With my own camera, for instance, there is a table at right angles to the optic axis and the tilt is the angle that Print II should make with that table, the shorter side of the trapezoid being nearest to the lens. The swing-back is to be tilted at the same angle but in the opposite direction.

The negative obtained in Stage III will have the proportions of the undistorted specimen, apart from the effects of flattening, but it will be too small. It may be enlarged to the required size in any ordinary enlarger. My fig. 3 has been enlarged so that the long side of the rectangle is 1·32 times as long as the side of the square in fig. 1. The two figures are accordingly on the same scale, fig. 3 showing the appearance before distortion and fig. 1 the present appearance, after distortion.

DISCUSSION OF THE RESULT

The accuracy of the result depends upon two things :—(1) The precision with which the values of *a* and *b* have been determined ; (2) the exactness with which photography has, in effect, reproduced those values.

The values of *a* and *b* were calculated from the angles α and β. Those angles were measured to the nearest half-degree and may, accordingly, be a quarter of a degree out, either way. It will be convenient to assume a square with 2½ in. sides, as in Pl. VII, fig. 1, and to calculate the sides of the original rectangle :—(A) If the angles α and β were each a quarter of a degree larger than the actual measurement ; (B) if they were as measured ; and (C) if they were each a quarter of a degree smaller than the measurement. The results are shown in the following table :—

	Short side.	*Long side.*
(A) .	1·91	3·27
(B) .	1·90	3·30
(C) .	1·88	3·32

The figures are calculated to the nearest hundredth of an inch. The correct form of the rectangle must lie between (A) and (C).

There are several possible sources of error in the photographic process. The most troublesome of them, because its effects are variable and cannot be foreseen, is that the paper base of the prints, after the prolonged washing which is necessary, may not contract uniformly. The paper is carefully chosen by the makers but small discrepancies do sometimes arise from this cause. The prints should be mounted dry, preferably with adhesive tissue. Not having the apparatus required for this process, I was compelled to use a mountant and this may introduce additional small errors.

The square surrounding the specimen was drawn upon the slab of rock, and since the surface of the slab is rather uneven the figure on the photograph is not exactly a square. Attention may be drawn especially to the lower side, which in Print I is not quite a straight line. The effect of this upon the final print will be discussed later. As a test of the subsequent working it would be better to draw the square upon Print I; but as a measure of the degree of accuracy obtainable by the whole series of processes it is better, I think, upon the slab itself.

In Stage II it is not easy, without specially designed apparatus, to set Print I at exactly the calculated angle with the optic axis of the camera. Provided that everything else is truly adjusted and that the subsequent processes are carried out correctly, the effect of a small error in this angle would be that in the final print the rectangle would not have exactly the calculated proportions, but it would still be a rectangle.

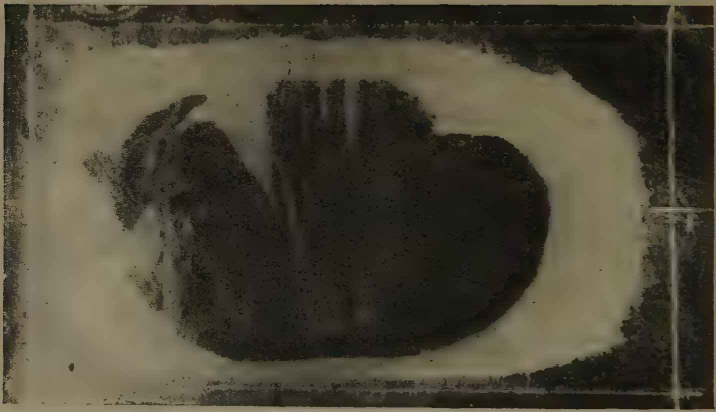
It is even more difficult to ensure that in Stage III the print and the swing-back are inclined at the proper angle. An error here may alter not only the proportions of the figure but also its angles, so that it may not be strictly rectangular. In this stage I found it necessary to unscrew some of the fittings of the camera, in order to allow the swing-back to be sufficiently inclined. This was, indeed, my chief difficulty throughout the whole process. It was necessary to prop the swing-back up, and to fix it at the proper angle was far from easy. Another trouble that arose here was that with the swing-back at this inclination the camera would not close sufficiently for reproduction the same size. I was forced to use a magnification of about one and a quarter. This would make the rectangle too wide in proportion to its length; but calculation showed that the extra width in fig. 3 would be less than a hundredth of an inch.

This chief defect in fig. 3 is that the angles of the enclosing figure are not exactly right angles. The worst is that at the bottom left-hand corner. This is due to the fact that, for reasons already explained, the bottom line of the "square" in Print I is not quite straight, but curves slightly downwards to the left side. In Print III this line is foreshortened and therefore the curvature is more marked. It is probable, also, that the print and swing-back were not set at exactly the correct angle and the camera was not centred on exactly the same spot as in Stage I.

The length and breadth do not differ from the calculated figures by more than a hundredth of an inch; but for the reason already mentioned the left-hand side is a little too long.

No one who possesses a long-focus and a short-focus lens should be deterred by the difficulties which I have mentioned. The square drawn upon the specimen or on the first photograph is a very severe test, and the errors that may creep in are so small that without such a test they would be scarcely perceptible to measurements made with the naked eye.

80—L



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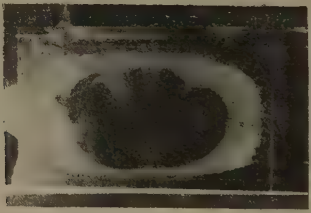

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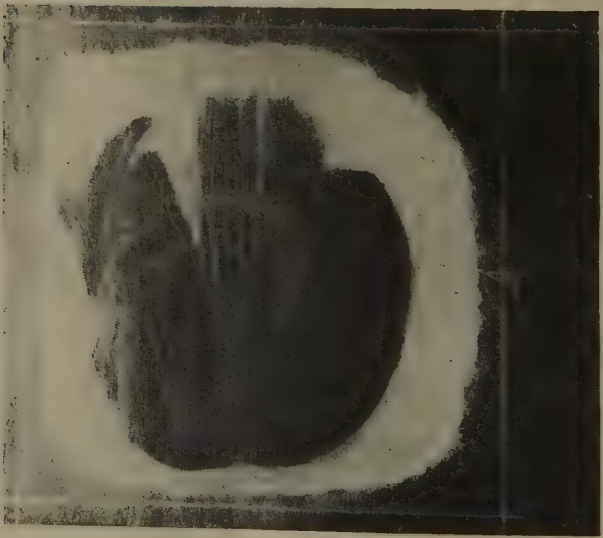

1

CONDITIONS NECESSARY

For exact results by this method three conditions are necessary. (1) The specimen and the rock in which it lies must have yielded uniformly to the pressures exerted upon them: there must, for instance, be no wrinkling or crumpling of the specimen or of the laminae that compose the rock. (2) It must be possible in some way to determine the directions of the axes of the strain ellipse in the plane of the specimen. (3) In the specimen there must be a pair of recognizable directions which were originally at right-angles, but which are not so now.

In the specimen figured it is the tail that enables us to fix the direction of the axes. The median line is still at right angles to the axial rings, as it was originally. This can only happen if those directions coincide with the axes of the strain ellipse. But sometimes there are other ways in which the direction of those axes may be determined. If on the same slab there are two specimens which lie obliquely to each other, and if each of them shows a pair of directions which were originally at right angles, it is always possible to determine the directions of the axes. If, in one of them the pair is still at right angles, the problem is the same as ours was—it makes no difference whether the two specimens are parts of the same individual or not. If in both specimens the originally rectangular directions are now oblique the direction of the axes can still be determined but the calculations are more complex.

A small amount of wrinkling will not produce any serious error in the result, and may, indeed, be useful. The wrinkles usually run nearly in the direction of the major axis of the strain ellipse and are often the only clue we have to that direction.

EXPLANATION OF PLATE

1.—Print I. Direct photograph of specimen of "*Ogygia scutatrix*, Salter". × ⅝.
2.—Print II. Oblique photograph of the same specimen.
3.—Print III. Photograph of the same specimen with the distortion corrected. × ⅝.

The So-called " Axial Granite Core " of the Himalaya : its Actual Exposure in Relation to its Sedimentary Cover.[1]

By N. E. Odell

WHEN recently on military duty in India, the writer was in correspondence with Mr. D. N. Wadia on the known distribution of granite within the ranges of the Himalaya, arising out of a statement by Mr. Wadia in his General Presidential Address to the 29th Indian Science Congress, 1942, on " The Making of India ". Therein it was declared (p. 7) : " In these earth plications masses of crystalline igneous rocks, granites, from the depths of the earth, have been pushed up through the sedimentary cover and now occupy the central zone of highest elevations. The sublime snow-capped peaks of the Himalaya from Mount Everest to Nanga Parbat, all are built of this axial granite core," etc.

Again, in Wadia's *Geology of India* (2nd ed., p. 17) it is stated : " There is reason to believe that the gneiss and granite composing the majority of the high peaks of the Himalaya belong to the intrusive category rather than to the old Archaean foundation ; they probably mark zones of special elevation connected with the welling up of acidic magma at certain points at the time of the uplift of the mountains."

This prevalent idea of the dominantly granitic axis of the Himalaya, irrespective of course of the mechanism by which the granite had been emplaced, had been established and further emphasized visually by the very generalized structural sections across the Range, constructed in the first place by H. H. Hayden as representing the official view of the Geological Survey of India. These sections appeared in *Geography and Geology of the Himalaya Mountains and Tibet* (1908), pt. iv, pl. 38 ; they were repeated in the 2nd ed. in 1933. In two of the sections carried across the middle and eastern portions of the range is shown a mass of undifferentiated granite and crystalline rocks occupying the central massifs of Nanda Devi and Kangchenjunga respectively. Moreover, in the text of part i, in the chapter entitled " The Geology of the Great Peaks " (in both editions), Hayden declares " it has thus been found that almost all those [peaks] of 25,000 feet or more in height are composed of granite, gneiss, and associated crystalline rocks " ; but he adds guardedly : " Although our experience leads us to assume that all the highest peaks are composed largely of granite, many more observations must be made before this can be positively asserted to be the case." The 2nd edition of this work, in the light of the findings of the earlier Everest Expedition, was able to correct the assertion of the 1st edition that " the Everest group is composed chiefly of granite and gneiss " ; but both editions err in their presumption that " to the west of Nepal we are on surer ground . . . the high peaks such as Nanda Devi, the Kedarnath group, and Kamet, are all composed of granite and gneiss, with gneiss and schist on their flanks.''

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[1] In a letter to *Nature*, 150, p. 379, dated 26.9.42, the writer summarized in briefest fashion the subject of this present note. Sir Lewis Fermor, in the same journal, p. 725, reviewed Wadia's Presidential Address to the Indian Science Congress.

The time-honoured, though mistaken, view that the Himalayan axis is thus mainly composed of granite or intrusive gneiss is to be attributed to the pioneer work of General C. A. McMahon particularly, and a few other investigators such as R. D. Oldham, in the seventies and eighties of the last century. It is true that McMahon (1884 and 1887) showed from his examination of the rocks of Simla, Dalhousie, and some other districts in the north-west, that much of what was formerly considered to be representative of the Archaean gneisses of the Peninsula proper was, in fact, intrusive orthogneiss ('' gneissose granite '' was his adopted term), and was therefore very much younger in age; but there appears later to have been altogether too much sweeping generalization based upon this view, and extrapolation to other parts of the Great Himalaya Range. McMahon's useful function consisted in correcting F. Stoliczka's (1886) premature conclusion that the '' Central Gneiss '' (Stoliczka's own term) as a whole was the oldest of all Himalayan rocks and was therefore Archaean, but the former's zeal swung the pendulum too far. We find '' official '' blessing, however, given to McMahon's view by Medlicott and Blanford in *A Manual of the Geology of India* (1879, p. 629) in such statements as : '' this granite is pre-eminently the axial rock of the main Himalayan range,'' and again, '' it occurs in veins and dykes of every size, sometimes forming the massive core, up to the summit, of the highest mountains.'' But we know now that a great deal of this so-called '' Central Gneiss '', which was mapped over large areas by Stoliczka, and even earlier in Garhwal by General R. Strachey (1851), must be considered, as indeed was claimed by them, representative of the oldest, and undoubtedly pre-Cambrian, rocks of the chain, rather than predominantly the youngest rock as stoutly maintained by McMahon. In fairness to McMahon it should be mentioned, however, that even in one of his '' type '' areas (Dalhousie) he was prepared to admit the presence of gneiss of sedimentary origin, and to concede for the general case—'' I must not be understood to deny that in the N.W. Himalayas we have to deal not only with granite and gneissose granite, but also with true gneiss '' (1884, p. 70).

Now, exploratory expeditions of recent years into the heart of both the Central and Eastern Himalaya, have enabled close examination to be made of some of the higher and more inaccessible peaks, and revealed that granite plays a far less important rôle, and occupies a much smaller proportion of the bulk of the inner ranges, than had earlier been considered to be the case as a deduction from the work of McMahon and his contemporaries.

In the Central districts of Upper Garhwal and Kumaon, in the Nanda Devi group and other ranges extending eastward into Nepal, the writer found in 1936 that altered sedimentary rocks such as slates, quartzites, and siltstones, with crystalline limestone and schist, compose by far the greater number of peaks of the high mountain tract. Granite was conspicuous by its absence over wide areas examined. Moreover, Heim and Gansser (Heim, 1937; and Heim and Gansser, 1939), during their extensive wanderings in 1936, which carried one of them right through into Tibetan territory, ascertained the great thickness of sedimentary strata out of which the high summits of this vast region have been sculptured. The actual age of the greater part of the series, which seems to be almost entirely unfossiliferous, is quite another matter. Much hard travel in difficult country will in future be necessary if any kind of correlation is to be effected with such well-mapped areas to the westward as Simla and neighbourhood (Pilgrim and West, 1928; Auden, 1934; and West, 1939), or Spiti (Hayden, 1909), or Lower Garhwal (Auden, 1934 and 1937). Moreover, the supposed highly involved Alpine tectonics in this area, invoked in recent years by Auden and West in particular and lately by Heim, will if confirmed make these correlations a task of the greatest difficulty.

The main peak of Nanda Devi was found by the writer (Odell, 1937) to consist mostly of light, often friable, sericitic schists and calc-rocks, with siltstones in the highest outcrops above 25,000 feet. No igneous elements at all were in evidence, not even aplite or pegmatite veins. Gansser, however, has surmised (Heim and Gansser, 1939) that seen from afar dykes of tourmaline-aplite appear to be present in the upper part of Nanda Devi East, the lower twin summit of the main peak. But Dr. J. Z. Bujak, a member of the Polish Expedition of 1939, who reached the top of Nanda Devi East, has not been able to confirm this observation of Gansser. Indeed, photographs rather suggest that the prominent bands running horizontally across the east face of the mountain may be resistant strata consisting probably of the known quartzitic components of the series.

Incidentally, the detailed results of my own work carried out during the Nanda Devi Expedition, 1936, have suffered a grave setback by the loss on a wartime voyage to India of my partially completed papers, maps, and field-notes. It is my intention later to try and make good the description of the rocks of the Nanda Devi massif therein given, and it is hoped that this may provide some areal amplification of Auden's stratigraphic and tectonic findings in the adjoining districts to the southward.

As far as the Eastern Himalaya is concerned, the work of Heron (1922 (1)), Wager (1934), and the writer (1925) has shown that in the Everest group and all along the Sikkim- and Bhutan-Tibetan frontier the higher ranges are mainly composed of slates, quartzites, and siltstones, and thick (often impure) limestones. Everest itself and its satellites are carved out of a thick series of slates, schistose siltstones, and crystalline limestones, injected in places by aplite, which is often richly garnetiferous or/and tourmaline-bearing. Even the conspicuous "Yellow Band", the light brown "granite band or sill", reported by G. I. Finch in 1922 (Heron, 1922 (2)), which extends from the "North-East Shoulder" westwards under the culminating pyramid of Everest at an altitude of about 27,000 feet, was ascertained in 1924 by me and confirmed in 1933 by Wager to consist of altered calcareous sandstone (schistose calc-siltstone) and schistose marble, with pelitic interbeds; whilst the base of the topmost pyramid was found to be of dark calc-rocks, varying from fine-grained biotite-quartz-schists to nobbly grey marble. No nearer than a locality some

40 miles west of Everest, deep down in the Rongshar valley (Odell, 1924), was found the typical Himalayan augen-gneiss in a large mass of indeterminable form and extent, and at the time ascribed to McMahon's granitic core of the range ; but no other comparable mass was seen in the neighbourhood. It is of some interest that the lithological character of the succession, both in this district and also farther west in the central portions of the main range, implies in large part a shore facies of the Tethys Sea. The absence of fossils from the Everest Series has, again, made the matter of age uncertain ; but Carboniferous to Lower Permian appears homotaxially to be the upper limit. Important contributory evidence of this age has recently been given by Wager (1942), with the valuable palaeontological collaboration of Drs. Helen M. Muir-Wood and K. P. Oakley (1941), from material collected in 1933 in the northern Sikkim Himalaya, where a lithologically similar series occurs bearing a corresponding relationship to the rocks further west along the borders of the Tibetan plateau.

Paragneisses and schists of presumably lower Palaeozoic and/or Archaean age are to be found in the lower parts of many of the mountains throughout this eastern region, but undoubted orthogneiss or granite is restricted mainly to the base of the chain in certain districts only, with apophyses of pegmatite or aplite extending upwards in some areas into the sedimentary series of the main peaks.

Dyhrenfurth (1931, p. 300) considers that the banded gneiss of Kangchenjunga itself is intrusive, though with a high proportion of original sedimentary gneiss and schist intercalated in it. He says that the preponderance of paragneiss increases northward in the Jongsong La and Upper Lhonak. This I am able to confirm from my own observations in 1938 when crossing the Chorten Nyima La ; but I cannot agree with Dyhrenfurth that the form of the injected gneiss (the " Central Gneiss ") is laccolithic. An important, and to him surprising, result of his expedition of 1930 was the discovery that the top of Jongsong Peak (24,600 feet) consists of limestone and calcareous shale (so named), considered to be Triassic in age.

At the north-western end of the Himalaya, in Kashmir and adjoining districts, the " Central Gneiss " of the early workers was at one time regarded as igneous, as already cited, and presumably of Archaean age. While later investigations have confirmed the igneous (i.e. granitic) character of a good deal of this complex, yet its age as a whole has been shown to be representative of a number of different geological periods. The magnificent summit of Nanga Parbat (26,620 feet), the culminating point of the Punjab Himalaya, according to Wadia (1932) and the German mountaineers (viz. Misch, 1935), consists almost entirely of finely schistose biotite-gneiss (paragneiss) with interbedded marble, graphite-schists, etc., of Salkhala (i.e. Archaean) age. Through this paragneissic complex are injected sheets and bosses of gneissose granite of two later periods. Conditions in many areas are necessarily extremely complex, and Wadia (*Geology of India*, p. 66) has correctly appreciated the fact that " these granites have (in places) passed into gneisses by assuming a foliated structure, while the Archaean gneiss proper has assumed the aspect of granites, owing to the high degree of dynamic metamorphism. It is again quite probable that a certain proportion of the central gneiss is to be attributed to highly metamorphosed ancient (Purana) sediments ". That a great deal of the so-called " Central Gneiss " is ultimately paragneiss, and not orthogneiss or granite (*sensu stricto*), is thus evident. Even Middlemiss in 1896 from his observations in the district of Hazara, bordering on Kashmir (*Mem. G.S.I.*, 26, p. 273), when commenting on this same controversy, declared that a " question of this kind seems to be a gratuitous undertaking, inasmuch as in certain ultimate stages of both rocks (i.e. ancient gneiss and foliated granite) modern opinion seems to be inclining to the view that they may be not only structurally constituted alike, but, within limits, functionally act alike ", a statement that was itself anticipatory of much present-day hypothesis of well-founded character.

But it is the writer's principal purpose to emphasize that a great deal more hard exploration and mountaineering will be necessary to determine how much of the real intrusive granite is derived from large " subjacent " emplacements, and how much may be attributed to smaller concordant injections of a phacolithic or other kind, resulting from contemporaneous or pene-contemporaneous orogenic movements. Moreover, there is evidence that later vertical movements of the block type have been responsible for the exposure of some of the granite bodies to be seen in the Great Himalaya. The immense fault-scarps to be found along some sections of the northern side of the main chain have in places exposed considerable thicknesses of sedimentary gneisses together with their deeper injected granitic elements. Chomolhari in northern Bhutan, and many of the mountains along the northern frontier of Sikkim, which tower above the plateau of Tibet, are notable cases in point (Odell, 1925). In the present writer's opinion, with which Dyhrenfurth (1931) concurs, it is to these local elevatory forces of recent date, acting in excess of general denudational processes that the supreme height of the Everest and Kangchenjunga massifs, standing 6,000 feet approximately above the average of their neighbours, can alone be due : nothing else can explain the often fresh and unweathered mountain walls, which rise sheer to heights of 6,000 to 10,000 feet above their bases, and extend for many miles round the massifs.

Since many observational data must be gathered before we can be certain of the real form and origin of the granite emplacements, it is premature to speak even of batholiths, *sensu stricto*, in any part of the main range. As cited above, we do not know as yet how many of the apparently immense intrusions are transgressive and of batholithic or (acid) sheet type ; or, on the other hand, how many may be concordant with the folding and consist of true phacoliths. In some districts, however, it does seem clear that the granites cut across the structures and were therefore intruded later than the main folding ; but it would appear to be almost a rule that they arrived only very shortly after that folding, and indeed have often been involved in its latest phase or phases.

In the Sikkim district Dyhrenfurth (1931) is of the opinion (by analogy with Alpine structure) that the Darjeeling gneiss (ortho- in part) has its roots 60 miles northward in Tibetan territory. Wager (1934) subscribes to a similar view of extensive nappe structure, and in his section through Sikkim he makes the granite of Chumbi the root and focus of the Darjeeling and other distant granitic masses.

For his own part the present writer is not prepared to accept such an extreme case of Alpine tectonics (with complete inversion of series) in this area as that envisaged by Dyhrenfurth and Wager on, it is considered, inadequate data. The writer's views of this matter conform more to those of Heim (1938), and imply restricted overthrusting of the so-called " relief " type, such as is to be found along the northern border of the Alps. This kind of overthrusting does not involve entire anticlinal reversal of an attenuated limb. Thrust-masses,[1] it is evident, are to be found locally in the area, viz. that beneath Everest and Makalu, but wholesale reversal of a great part of the series, embodied by far-travelled *nappes de recouvrement*, has yet to be proved, and much further field-work will be necessary before major Alpine tectonics can here be deemed to be a safe working hypothesis. As observed from the Rapiu La at the foot of the north-east ridge of Everest (Odell, 1938), a local thrust-plane runs from Makalu beneath Lhotse and Everest, and movement along it has given the northerly tilt of the Everest block itself, and the awkward dip, from the climbers' viewpoint, of the rocks of the north face. Moreover the top of Makalu appears to be composed of a portion of a great sheet of light granite whose injection probably accompanied the above movement.

As far as the petrological character of the Himalayan granite is concerned, it is known that more than one species, and age, occur in different parts of the region. A biotite-granite is found predominantly in the main chain, and is the type usually referred to in the literature as " Himalayan Granite ". In addition, there is a granite composed of schorl, plagioclase, muscovite, and beryl, which is found in some areas cutting the biotite-granite, but which appears to be merely a pene-contemporaneous phase of the latter. Lastly occurs a hornblende-sphene-granite, which is clearly the youngest of the type and outcrops chiefly on the Tibetan side of the range. But much further work is required to determine the relative distribution and proportions of these and any other varieties throughout the Northern and Central Himalayan Zones.

It should be added that the " Geological Map of the Himalaya and Tibet " (Burrard, Hayden, and Heron, 1933) displays in the present state of our knowledge, or ignorance, but a very moderate amount of granite as such throughout the length and breadth of the chain, although areas underlain by " Unclassified Gneiss " do include, of course, some granitic intrusive rocks. But from the existing data we are not in a position to say explicitly that the large acid intrusives lie eccentric to, and on the lee side of, the main folded zone, as is the case in many well-known orogenic belts, such as the Alpine, Hercynian, and particularly the Appalachian. Some occurrences, however, do seem to be thus eccentrically disposed, especially at the north-western end of the Himalaya. This disposition, it may be remarked, is of such wide occurrence and significance that W. H. Bucher in his *Deformation of the Earth's Crust* (p. 274) would give it the status of a "law".

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[1] There is, perhaps, even at this relatively mature stage of tectonic nomenclature, something to be said for Heim's plea (in a footnote to the paper referred to) for the use in English of " thrust-mass " or " thrust-sheet ", rather than " nappe ", which in French can actually have several geological meanings, including even that of a *normal* superposition of strata. The term " nappe " would seem, indeed, to be badly overworked.

The writer hopes at some future time to publish further details on this subject, giving his views of the tectonics of the eastern portions of the chain, with petrological descriptions of the rocks of the Everest and Nanda Devi areas in particular.

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Solution Etching of Detrital Staurolite

By Geoffrey Bond

ATTENTION has recently been directed, particularly by the writings of Boswell (1942) and Smithson (1941, 1942), to the instability of detrital minerals. In nearly all cases where etching of mineral grains has been described the rocks have been deposited under water, as members of a continuously sedimentary series.

While investigating the heavy mineral suites of sandy formations in Southern Rhodesia, the writer found etched grains of staurolite and kyanite in one sample only. Since this rock is of aeolian origin and is directly overlain by a contemporary flow of basalt it seems worth a short description.

The locality from which the specimen was obtained lies 25 miles north of Bulawayo along the main Victoria Falls Road, being a small roadside quarry 1 mile south of Hilda's Kraal. The rock is a red, flaggy, rather friable, well-jointed sandstone of aeolian origin lying beneath the first lava flow of the Nyamandhlovu series, and is of Karroo age. The hand specimen was taken some 20 feet below the base of the flow.

The scanty heavy suite is made up of zircon, tourmaline, and staurolite (common), and rare apatite, kyanite, sphene, and opaques. Nearly all the staurolite grains show etched terminations. The zircons and tourmalines are beautifully rounded. Except for their etched terminations the staurolites show a sub-rounded form.

These grains extinguish parallel to the slow axis which, therefore, corresponds to the c = Z axis of the crystal. They usually give an excentric " compass needle " isogyre, so that the face on which they lie must contain the point of emergence of the optic axis. Since the optic axial plane of staurolite is (100), the grains must be lying on the (010) face, being terminated by (001). The pleochroism is :—

Z = golden yellow
Y = pale yellow to colourless.

Projections occur only on (001), that is the basal plane of the crystal, and in the first example observed, on one end only. Other grains in the same slide show them at both ends. No grains have been seen with projections on any other face. From their position, and optical orientation of the grain, it can be seen that they are probably bounded by the (101) form, and that they are in perfect optical continuity with the remainder of the grain.

Staurolite possesses two cleavages which are given in Dana as :—

(010) Distinct but interrupted.
(110) In traces.

The first of these determines the orientation of most of the grains of staurolite in these sands, and the traces of it can often be seen on the top surfaces of the grains. The b-axis of uncleaved crystals is usually the shortest, but the (010) cleavage has produced flakes in these sediments which are flattened so that the a-axis is the shortest. Thus the solution planes (Lösungsflachen) of staurolite do not coincide with the cleavages.

Although a large number of slides from the sandy formations has been examined etched grains have only been seen in one sample, from the sandstone immediately underlying the first lava of the Nyamandhlovu group. Except in the lowest member staurolite is rare or absent in samples from this group, but common in Forest Sandstone and Kalahari Sands. It is not inferred that staurolite was originally present, and has been removed by solution. Etched grains represent the first stage in some such process, but the mineral assemblies in this group are quite different from the Forest Sandstone and Kalahari sands, notably in the varieties of tourmaline present. It does suggest that the lava immediately above supplied the agent which attacked the grains of staurolite. In hand specimen the rock is less consolidated than many Forest sandstones in which staurolite grains remain unaffected, as they do in the hard Kalahari quartzite described by Frost (1927), whose slides have been re-examined and found to contain staurolite. The nature of the attacking solution is obscure, but its connection with the overlying basalt seems clear. Other minerals mentioned by Smithson as unstable in sediments and showing etched faces included garnet, kyanite, and apatite. Garnet is absent and the last two extremely rare in this rock, but small kyanites show much raggedness at the ends, though it was not possible to determine the forms produced.

In the Yorkshire Jurassic, solution etching of various minerals is associated with outgrowths on zircon, an effect so far only recorded from Middle Jurassic deposits. In this case an aeolian sand affected by solutions from an overlying basalt, beautiful etching of at least two minerals has been produced, but the most careful search has not shown a single grain of zircon with outgrowths, although it is by far the commonest heavy mineral in the rock. Conditions which will cause etching of staurolite and kyanite by solution are, therefore, not necessarily those which produce outgrowths on zircon.

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I wish to record my gratitude to Dr. Arnold, Director of the National Museum of Southern Rhodesia, for allowing me to make use of the facilities of the museum during my stay in Bulawayo.

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REVIEWS

GROWTH OF THE NORTH AMERICAN ICE SHEET DURING THE WISCONSIN AGE. By R. F. FLINT. *Bull. Geol. Soc. America.* December, 1942.

The evidence of separate Labradorian and Keewatin centres of radial glacial flow is confined almost wholly to very late Wisconsin time and indicates that these centres shifted their positions widely even during that short time. There is no evidence that these centres ever were the sites of independent glaciers ; their importance has been over-emphasized. The North American ice sheet, during the Wisconsin maximum, was recognized as a single mass and named the Laurentide ice sheet before the names Labradorian and Keewatin were applied.

The Laurentide ice sheet is believed to have originated as mountain glaciers chiefly in the conspicuous highlands of eastern Quebec, Labrador, and Baffin Island. Nourished by moist maritime air masses derived mainly from the south and south-east and moving northward and eastward, these glaciers coalesced into piedmont glaciers. By continued growth southward and westward toward the principal sources of their nourishment, the piedmonts thickened and spread, burying the highlands in which they had originated. Ultimately they formed a vast ice sheet that extended from the east coast to the Cordillera. Expansion toward the east was prevented by the deep water of the Atlantic, in which the ice broke up and floated away.

Glacial-anticyclonic winds are assumed to have been subordinate to cyclonic storms in nourishing the ice sheet. The Labradorian, Keewatin, and other centres of outflow recorded by striae were broad low domes on the surface of the ice and were caused by exceptional concentrations of snowfall. While the ice sheet was shrinking, these domes shifted their positions.

PEAT : RESOURCES IN ALASKA. By A. P. DACHNOWSKI-STOKES. Technical Bulletin 769. U.S. Dept. of Agriculture, 1941. pp. 84, with 24 figs. Price 15 cents.

Peat in its different varieties already has many industrial uses, and it seems likely that many more will eventually be found. As is only natural, taking the climate into account, the resources in Alaska are enormous, the area covered by peaty deposits of some kind being reckoned at 110,000,000 acres. Most of these deposits are locally called muskegs, and may be described in general terms as natural ground covered more or less with sphagnum moss, tussocky sedges, and an open growth of scrubby timber, mostly conifers. They therefore resemble the mosses of Scotland and northern England rather than the so-called peat of the fens. Muskegs are not necessarily flat, but may be formed on slopes, and are often distinctly convex, like sponges full of water. These are apparently similar to the kind of British peat-bogs that occasionally burst and do much damage. It is interesting to find that many of the constituent plants are species well known in northern Europe. Usually the ground is permanently frozen below 3 or 4 feet from the surface, but plants such as heaths, sundew, cotton-grass, and cranberry flourish all the same.

GLAUCONITE SAND OF BRACKLESHAM BEDS, LONDON BASIN. By K. P. OAKLEY. Wartime Pamphlet No. 33, Geological Survey, pp. 28, with 5 figs. 1943. Price 1*s.* 6*d.*

Glauconite has several industrial uses: as a source of potash, in paint-making, and in water-softening. Hitherto supplies have been imported as the Cretaceous Greensands are of too low grade. The object of this pamphlet is to show that the Bracklesham Beds of the London Basin contain abundant supplies of high grade material in Surrey, Berkshire, and north Hants, even running up to 95 per cent in some beds.

The composition and origin of glauconite are discussed in detail. It is now known to belong to the mica family, but the chemical formula appears to be very complicated. In the Bracklesham beds at least it is considered to be allothigenic, not however derived from pre-existing rocks but of penecontemporaneous origin: that is, re-worked by currents after formation, but its ultimate genesis is still obscure. It can apparently be formed by diagenesis from a variety of substances, but the source of the potash appears to be unknown. Although not here mentioned it may be pointed out that there are considerable resemblances in the manner of occurrence of glauconite and chamosite and it is conceivable that both may be of bacterial origin, as long ago suggested for chamosite by Cayeux.

R. H. R.

THE ORIGIN OF THE CAROLINA BAYS. By DOUGLAS JOHNSON. xvi + 341 pages, 44 illustrations. Columbia University Press, New York, 1942.

This book, the latest addition to the " Columbia Geomorphic Studies ", No. 4, is Professor Johnson's crowning achievement. The volume is considerably thicker than any of the three earlier " studies ", and one naturally wonders at first how it has been possible to attenuate a study of the little known Carolina " bays " so as to fill 350 large pages; but not a word is wasted. Some are accustomed to express themselves briefly, others at greater length. The author has an expansive style, and it is a matter for congratulation that his publishers have made it possible for him to give admirable expression to his views.

The Carolina " bays ", despite the insignificance of their relief, are a major feature of the earth's surface; though, as Professor Johnson points out, they are in reality very much less conspicuous than air photographs make them appear. If the camera cannot lie, it can at least exaggerate relief. These shallow pans of oval outline and uniform orientation are, however, the dominant relief features over a vast area of the North American coastal plain.

The theory that these depressions are scars resulting from impact of meteorites is finally disposed of. It has served its turn, however ; but for the publicity given to the " bays " by the exploitation of the meteoritic hypothesis, and the necessity of testing the hypothesis, it is doubtful whether such a thorough study of the landforms of this region as we now have before us would have been undertaken.

The hypothesis of complex origin (artesian-solution-lacustrine-aeolian) is well supported and may now be regarded as firmly established. The analysis of the problem is very thorough ; it is not mere theory, but is based on an immense amount of very difficult field work. This makes the whole study conspicuously a model of scientific method. It is equally a model of literary style.

One cannot but admire the gentle treatment—firm but gentle—which the author metes out to theories he disproves. The book is the work of a teacher and a scholar—and, above all, of a gentleman.

C. A. COTTON.

CORRESPONDENCE

HYPOSTOMES OF GIRVAN TRILOBITES

SIRS,—Since the publication of my paper on "Hypostomes of Some Girvan Trilobites" (*Geol. Mag.*, 1943, pp. 56–65) Dr. C. J. Stubblefield has kindly drawn my attention to a paper by Dr. F. B. Phleger, entitled "Further Notes on the Lichadacea" (*Journ. Paleont.*, 1937, pp. 253–6), which I particularly regret having overlooked, since it deals with the backward extension of the hypostome in certain trilobites, a feature to which I drew attention in my paper. Dr. Phleger was able to develop these views regarding the anatomy of the mouth region (already indicated in an earlier paper, *Journ. Paleont.*, 1936, pp. 593–615) after a visit to Britain during which he saw a number of specimens with large hypostomes. These included some examples in my own collection which he described, including one which had been figured previously by Dr. F. R. C. Reed (Girvan Trilobites, Supplement 3, *Paleont. Soc.*, 1935). It may be useful to point out that the specimens of *Platylichas crescenticus* described by Phleger (1937, p. 254) as BG. 2080, 2080*a*, and 2082 are parts of the same individual. Phleger was aware that this was so in the case of BG. 2082 and 2080, but apparently not concerning the part which he recorded as BG. 2080*a*. The "impression of the upper surface" of the cephalon figured by Reed (*op. cit.*, pl. iii, fig. 16) is numbered BG. 2082. The internal cast of the cranidium Reed figured in his plate iii, fig. 13, and the opposite side of this fragment, which shows the ventral view of the hypostome cast, in plate iii, fig. 15. But whereas this latter fragment is recorded as BG. 2082 by Reed, it was referred to by Phleger as BG. 2080*a*. Another fragment, BG. 2080, "the impression of the lower surface" of the cephalon, which also shows the impression of the hypostome, is illustrated in Reed's pl. iii, fig. 14. Phleger's suggestion (1937, p. 254) that the hypostomes in BG. 2080 and BG. 2080*a* are of different length thus arises from a misunderstanding, since they are positive and negative faces of the same individual.

J. L. BEGG.

GLASGOW.
16th June, 1943.

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The Pre-Karroo Stratigraphy of Tanganyika

By G. M. Stockley

THE purpose of this paper is to discuss certain aspects of pre-Karroo (unfossiliferous) stratigraphy of Tanganyika and to make certain proposals, which are considered desirable in order to further geological research in East Africa and to aid in regional and detailed mapping. A summary of the unfossiliferous rocks, together with these proposals, changing the names of certain systems, is systematized in Table I. The suggestions embodied in this scheme are as follows :—

1. Limiting the name *Basement System* to the crystalline limestones, schists, gneisses, and granulites, previously termed the Lower Basement Complex or Lower Division Basement Complex.

2. Replacing the present name of Upper Division of the Basement Complex by *Nyanzian System.*

3. Introducing a new system, the *Kavirondian System*, to include those rocks previously and provisionally correlated with the Muva-Ankolean.

It is agreed by most of the geologists on the Tanganyika Geological Survey that a revision of these formations is overdue. The writer takes the responsibility for the following suggestions : they have been discussed with several of his colleagues and on the whole there is fair agreement. Stansfield Hitchen, senior geologist of the Kenya Geological Survey, has accepted these proposals insomuch as they touch on the same formations existing in Kenya.

BASEMENT SYSTEM.—The oldest rocks in the Territory consist largely of a complex group of metamorphic crystalline sedimentary rocks and some basic igneous rocks, classified hitherto under the general name of the Basement Complex. With regard to this System, Teale (1933) first stated that :—

> " Broad classification into an Upper Group and a Lower Group is possible but as detailed investigation proceeds, a number of minor divisions of more local importance will be found necessary."

Teale revised this statement three years later (1936), as follows :—

> " The Basement Complex is susceptible of provisional classification on lithological grounds into three age groups depending on the degree of metamorphism to which each has been subjected. It may be stated, however, at the outset that no sections have been observed showing the passage of one group into the next above, and it is more than probable that they are separated by vast unconformities."

TABLE I

Chronological Table of the Pre-Karroo Rocks of Tanganyika

Present Name.	*Proposed Name.*	*Lithology* (*type area*)	*Relationship to Igneo Chronology.*
Bukoban.	No change. Teale's name Uha System to be discarded. (Type area Uha.)	5. Red Beds. 4. Dolomitic limestone with cherts and interbedded shales at base. 3. Basaltic lavas. 2. Malagarasi sandstones and quartzites. 1. Dark to olive shales. (After Teale)	Penetrated by altere and fresh doleri dykes : lowermost quartzite may be veined with quartz
		Great unconformity and peneplanation	
Muva-Ankolean.	No change. (Type area Ankole and Karagwe.)	5. Kishanda Beds (pelitics). 4. Mtagata Quartzite. 3. Mabira Beds (pelitics). 2. Kafulu Quartzite. 1. Arena Beds (Metamorphosed pelitics). (Karagwe succession after Stockley.)	Cut by dolerites a norites ; intruded and peripherally metamorphosed granite : cut by mineralized quart veins, tin, tungste and tantalite.
		(In Karagwe the base is an intrusive contact)	
		unconformity	
Previously correlated with Muva-Ankolean.	Kavirondian System. (Type area N.E. Kavirondo.)	3. An upper division of felspathic grits at the base of which occur shale and siltstone fragments derived from the middle division. 2. A middle division, dominantly pelitic in character, and composed of siltstones and slates. 1. A lower division of felspathic grits and large stocky lenses of conglomerate. (After Hitchen)	Cut by all manner acid and basic dyk dolerites, epidiorit dacites and quar veins, often miner ized with gold. truded by young granite. Pebbles an older granite conglomerate.
		unconformity	
Upper Division Basement Complex.	Nyanzian System (Type area Musoma and Kavirondo districts)	4. Kuria Volcanics (dacites and quartz-porphyries). 3. Banded ironstones of both sedimentary and acid volcanic origin. 2. Acid volcanics, tuffs, and agglomerates ; and quartz-porphyries. 1. Basic volcanics, tuffs, and agglomerates ; and epidiorites. (Musoma succession after Stockley)	Serpentine intrusion. Pierced by numero dykes, varying fr acid to basic ; cluding epidiorit cut by younger a older granites : proof of minerali tion by older gran
		unconformity	
		(Not seen in Tanganyika)	

Lower Division Basement Complex.	BASEMENT SYSTEM. (Chiefly after Temperley and Teale.)	2. Crystalline Limestone Series, includes metacalcareous sediments and quartzites. 1. Metasediments, chiefly pelitics and psammites; also undifferentiated gneisses and granulites. Migmatites occur in all formations. Metadolerites, plagioclase-amphibolites and charnockitic rocks in lower series. Base not yet seen.	Cut by various dykes and intrusives though dolerites are rare. Deep metasomatic penetration by soaking causing migmatization. Massive coarse mica-pegmatites. Graphite-schists underlie No. 2.

The separation into three divisions was a step in the right direction towards the unravelling of the tangle of these formations. This evolutionary tendency was, however, somewhat arrested by Wade (1937) in the following year, in spite of the considerable amount of detailed field work which had been accomplished in the previous three years, especially in South-West Mwanza and Musoma districts. Wade states :—

"It is suggested that a better understanding of the subject can be obtained by regarding the Basement Complex as a single unit. . . . Therefore, if the Basement Complex be regarded as a unit, and if the Crystalline Limestones be recognized as marking a division in the Lower Division, and in similar fashion the Banded Ironstones as marking a horizon near the top, then it is contended that the usefulness of the proposed classification becomes greater and more easily comprehended, and that future field work will thereby be simplified."

The writer entirely disagrees with this suggestion, and takes the alternative view that the rocks hitherto classified as Upper Basement Complex should now be completely separated from the crystalline rocks of the Lower Division, and that they should be placed into a separate System, to be called the "*Nyanzian System*". It seems to him that the term "Complex" is scarcely applicable to a group of rocks comprising normal and well-defined volcanics and sedimentaries, most of which may be recognized and identified in the field and mapped as individual formations. Temperley goes as far as to state that the rocks of the Lower Division, in his opinion, do not constitute a "Complex".

The facts, which do not support the suggestion that these formations form one unit, may be enumerated :—

1. As Teale has pointed out, in no area in East Africa has it yet been demonstrated that the typical gneisses and granulites of the rocks of the Lower Division do grade into the type rocks of the Upper Division.

2. No limestones, comparable with the coarse crystalline limestones of the Lower Division, have as yet been found in any rocks of the Upper Division. As the crystalline limestones represent the less metamorphosed portion of the Upper Division, they should certainly be represented among the Upper Division : that is, if the former grades into the latter !

3. No relics of the Upper Division have as yet been found within the Lower. If these two divisions form a continuous series, folding should

have preserved instances of the less metamorphosed within those more metamorphosed.

4. Lithological differences between the two divisions are profound. Grantham and Temperley (1940) have summarized these differences in the following table :—

TABLE II

COMPARISON OF UPPER AND LOWER DIVISIONS OF THE BASEMENT COMPLEX
(After Grantham and Temperley)

	UBC	LBC
Original rocks (sedimentary).	Normal sediments rare, BI common, limestones absent.	Normal sediments abundant, limestones important.
(Igneous.)	Acidic and basic volcanics and intrusives abundant.	Basic minor intrusives dominant.
Metamorphism.	Low grade, meso- or epi-zone, hydrothermal alteration, no extensive migmatization proved.	High grade, hypo-zone, much metasomatism, extensive migmatization.
Type minerals.	Amphibole, chlorite, hydrobiotite.	Garnet, kyanite, pyroxene, amphibole, scapolite.
Texture.	Very fine grain.	Coarse grain.
Relation to later magmatic material.	Batholithic stopings, limited injection by dykes and veins, little soaking.	Deep penetration by soaking.
Attitude.	Steep dips, commonly vertical.	Stratiform, low to moderate dips.

When it is considered that the rocks of the Upper Division usually occur as roof pendants or curtains within the granite, while the rocks of the Lower Division are commonly situated and exposed over great distances extending from the periphery of the granitoid shield of the Central Plateau (everywhere exhibiting the same degree of metamorphism, whether near to or far from the granite : and containing garnet and kyanite from end to end), the above list of mineral and metamorphic differences can only be explained by vast differences both of age and general conditions of formation.

Lately the writer has had the opportunity, while investigating the Eastern Ulugurus Graphite deposits, of mapping in some detail a portion of the LBC terrain, and his study of the region south of the Ruvu River suggested the following succession :—

Eastern Uluguru Mountain Series. B. Metacalcareous Beds. (Top)

7. Upper crystalline limestone, quartz-granulites with one contaminated limestone band ; 2,000 feet thick.
6. Contaminated limestones.

5. Richly garnetiferous granulites.
4. Migmatite-gneiss.
3. Richly garnetiferous granulites.
2. Lower crystalline limestone, quartz-granulites with minor bands of migmatite, and richly garnetiferous granulites.
1. Metacalcareous granulites with some migmatite.

(Beds 1 to 6, 1,600 feet to 2,400 feet thick.)

A. Graphitic Beds.

5. No. 3 Graphitic gneisses and schists with some migmatite.
4. Metacalcareous granulites, undifferentiated ; with metadolerites and hypersthene-granulites.
3. No. 2. Well-bedded graphitic gneisses, granulites, schists, and migmatites.
2. Coarse amphibolites, many of which are garnetiferous, and migmatites.
1. No. 1. Bedded graphitic granulites, schists, and migmatites.

(Beds 1 to 5 at least 4,400 feet thick ; actual thickness unknown owing to faulting and folding.) (Base unknown.)

In Tanganyika the Metacalcareous Beds (including of course the thick crystalline limestones) are known extensively throughout the LBC terrain. They have been reported from the south, both near Lake Nyasa and near the Rovuma River, west of Newala, from Mahenge, from the corridor between the coastal sediments and the Karroo of the upper Rufiji River, from between Mahenge and Kissaki, from the Eastern Ulugurus, between the Central Railway and Handeni and also from the Masai Steppe. Observations show that the crystalline limestones are folded but the rocks beneath seem to be less so. The writer has recently in a departmental report suggested that migmatization in the Basement System is concentrated in the main axes of geo-anticlines, and that its effect diminishes towards the region of the major synclinal basins, occupied by the Metacalcareous Beds. As Temperley states (1942) : " This complex (LBC) has everywhere undergone regional metamorphism and large parts of it have been granitized, so that it now presents islands of metamorphic rock lying in vast tracks of stratiform migmatites or of granitic gneisses."

Finally, other Geological Surveys have tacitly assumed the separation of these rocks (the LBC and UBC) into two systems. Both Hitchen and Pulfrey (1938) differentiate between the Basement Complex and the pre-Muva-Ankolean (pre-Kavirondo Series of Kenya) and actually show that an unconformity exists at the base of the pre-Kavirondo Volcanic Series, which is correlated with the Musoma Series, that is, the UBC of Tanganyika.

NYANZIAN SYSTEM.—In view of the above considerations the writer proposes that these two divisions should henceforth be regarded respectively as :—

(2) Nyanzian System.
(1) Basement System.

The term " Nyanzian " is suggested because the best exposures and type areas are located around the Victoria Nyanza, especially in the districts of Kavirondo in Kenya and in the Musoma, Mwanza, and Kahama districts of Tanganyika. The Nyanzian System may be correlated with the Dalradian of British Systems, the Dharwar System of India, and the Keewatin of Eastern Ontario and Quebec.

The Nyanzian System consists chiefly of a series of acid and basic volcanics, with their tuffs and agglomerates and the Banded Ironstone Suite. The stratigraphy of the Nyanzian is exemplified by the geology of the area south of Lake Victoria, through Musoma District to Kavirondo on the northern shore of the lake (Kakamega). In Kahama District Grantham (1940) has included the following :—

(*c*) Banded Ironstone Suite.
(*b*) Acid Volcanics and quartz-porphyries.
(*c*) Basic Volcanics and metadolerites.

This agrees with the original Musoma Series of the writer (1935), but in Kahama there are more tuffs than volcanic rocks ; whereas in the region of Musoma District, from Mrangi to the sub-district of North Mara, tuffaceous sediments are subordinate to the rhyolites, spherulitic rhyolites, and trachytes. In the intervening region of the Serengeti Game Reserve these rocks are represented by a thick series of banded ironstones, argillites (? tuffs), grits, and phyllites. To the north in the Banagi-Ikoma area there are pillow lavas, andesites, and trachytes, which may be correlated with the Basic Volcanics.

In southern Kavirondo acid to basic lavas with tuffs and agglomerates are overlain by a Greenstone Series. In Central Kavirondo there exist in the north-west and north-east (*a*) rhyolites and sub-acid lavas, tuffs, and agglomerates, (*b*) intermediate lavas, and (*c*) basalts and dolerites. In the south-west the rhyolites are overlain by andesites, which are overlain by basalts, and these volcanic rocks are accompanied by their tuffs and agglomerates. In northern Kavirondo [1] there are banded ironstones, acid and basic volcanics, and dacites.

It seems apparent from these observations that in Kavirondo the Nyanzian consists of volcanics and that sediments (excepting pyroclastics) are relatively rare, if they exist at all. Low-grade metamorphic changes are common to all areas, but in the Mrangi-Buhemba belt of Musoma District shearing and carbonation are dominant. In this belt slabby masses of grey-green rocks are common ; thin slices prove them to be sheared and carbonated acid and trachytic volcanics. The writer named these the " Tombstone Formation " ; the reason for separating them from the less metamorphosed was twofold. These rocks frequently contain auriferous quartz veins, and they are often difficult to identify in the field with the same exactitude as the other rocks of the Nyanzian. Another reason may also be given : the name attracts the attention of the prospector to these rocks, and he will consequently not forget to prospect them thoroughly.

The dacites and dacite-porphyries, comprising the Kuria Volcanics of Musoma, are not prevalent in Kavirondo, but dykes of the same composition are known to be paulopost Nyanzian acid volcanics. Actually in Musoma District there are dacite and dacite-porphyry dykes of two ages ; the earlier are connected with the extrusion of the Kuria lavas and the others are post-granite in age.

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[1] In Kenya BI are known only from Northern Kavirondo : thus for considerable areas of Central and Southern Kavirondo, the Nyanzian consists solely of volcanics and pyroclastics.

KAVIRONDIAN SYSTEM.—The next proposal is the elevation of the Kavirondo Series and the North Mara Series to the status of a system. Originally the writer (1935 and 1936) correlated the North Mara Series with the Karagwe-Ankolean, but since he has been engaged in surveying the latter in north-west Tanganyika the provisional correlation has been revised. Also he has had an opportunity of seeing similar rocks in Southern Rhodesia. The original correlation was based on the relationship to the Musoma Series and to the younger granites. Though this relationship has since been confirmed in Kenya and elsewhere, he considers that the lithology of both the North Mara Series and the Kavirondo Series is not typical of the Muva-Ankolean, more especially the Karagwe-Ankolean of Uganda, north-west Tanganyika, and north-eastern Belgian Congo. In Tanganyika the Muva-Ankolean are characterized by great thicknesses of pelitic sediments (mica-schists, phyllites, shales, and slates) (*vide* Stockley, 1938) separated by bands of quartzites. The quartzites occasionally contain small and local lenses of conglomerates but never become extensively conglomeratic. The North Mara Series, on the other hand, and the Kavirondo Series are essentially conglomerates, coarse arkosic and felspathic grits and quartzites with subordinate pelitic beds. In Tanganyika the conglomerate is particularly characteristic and always associated with the Nyanzian volcanics. It is a hard indurated compact pebbly or bouldery rock, containing a great variety of older rocks, and the matrix between the pebbles forms a felsitic base not very different from the groundmass of the acid lavas and dacites. In northern Musoma and south-west Mwanza districts there are excellent exposures, proving that their age is post-BI and acid volcanics and pre-granite. The writer briefly described an examination of thin sections :—

" In thin section both rounded and angular fragments of quartz, felspar partly kaolinized (rhyolite) porphyry, hornfels, quartzite, and vein quartz make up their chief inclusions. As the pebbles and fragments become smaller and the coarser material becomes scarce, so does the difficulty increase of definitely establishing their clastic origin, since the groundmass becomes more and more uniform in character until a felsic microgranular base results."

In Kenya Hitchen (1937) has described the Kavirondo Series as follows :

" Under the microscope the typical grit of the lower division is seen to consist of a haphazard assortment of fragments of quartz, felspar, and felsitic matter (devitrified rhyolite, etc.), set in a finer detrital matrix of the same minerals. . . . The poor grading of the material, the high proportion of angular and sub-angular particles, and the remarkable freshness of the felspar, suggest rapid sub-aqueous accumulation. . . . Many pebbles of granites, quartzites, and schists were noted in the conglomerate at Kaluo, but in the Gegeya Kisendo area the pebbles are chiefly of volcanic rocks, including basalts, porphyritic, and non-porphyritic lavas of intermediate composition, many varieties of rhyolite and quartz-porphyry, and tuffs."

In certain cases the conglomerate consists solely of banded ironstone, in others of dacite-porphyry, in others of quartzite, while in another of an earlier granite.

The Muva-Ankolean of Ankole and Karagwe exhibit no such types, and it seems probable that these more indurated rocks of Kavirondo and Musoma belong to an earlier age. A stricter correlation, in the writer's opinion, is with the Shamva Grits, Eldorado Series, Ndutjana Sedimentary Series, and the Mbeza Sediments of Southern Rhodesia, all of which were once included within the Basement Schists, although separated from the underlying rocks by an unconformity. The evidence, which summarizes the main differences between the two formations, may now be tabulated :—

1. The North Mara Series and the Kavirondo Series are closely associated (commonly infolded) with the Upper Division of the Basement Complex.

2. The Muva-Ankolean of Karagwe, Ankole, and north-east Belgian Congo are never associated with the UBC.

3. The difference in lithology points to different climatic conditions which prevailed at the time of deposition. The North Mara Series (and its equivalent in south-west Mwanza Goldfield) were rapidly accumulated, suggesting a period of heavy rainfall. The climate of the MA was probably more uniform and equable, without bursts of heavy rainfall.

4. The folding which the two formations have suffered is dissimilar. The MA is much less steeply folded than the North Mara Series.

Stansfield Hitchen in a private letter to the writer agrees with this rearrangement. The writer suggests the name Kavirondian System is suitable, because more extensive outcrops of these rocks occur in Kavirondo and they have been studied in some detail by Kenya geologists. The type sequence is that described by Hitchen (1937) :—

"1. A lower division consisting of felspathic grits and large stocky lenses of conglomerates ;

"2. A middle division, dominantly pelitic in character and composed of siltstones and slates ; and

"3. An upper division of felspathic grits at the base of which occur shale and siltstone fragments derived from the middle division."

An objection might be raised, advancing the view, that the Muva-Ankolean of Karagwe may be a pelitic facies of the conglomerates and grits of the eastern and southern Lake Victoria region. There is no direct evidence either to prove or disprove this objection. On the other hand, both in Southern Rhodesia and in the eastern Lake Victoria region massive compact conglomerates and felspathic grits prevail and form a constant feature. In other formations in Africa, well exemplified in the Karroo System of South Africa, it is possible to differentiate the various series and beds on lithological grounds alone.

Bukoban System.—Separating the older rocks and the granites from the youngest unfossiliferous sediments there is a great unconformity, which probably represents a vast interval of geological time. The granites which had invaded all the previous formations had been so denuded previous to the deposition of these sediments that for considerable areas the granite formed the floor, on which they were deposited. There is strong evidence for a fossil peneplain, forming the sub-Bukoban surface.

The writer proposes to correlate the Bukoba Sandstones with a part of Teale's original Uha System. The name Bukoban assigned to a System is in this case unfortunate ; because few details are known about them. No succession has been determined and their stratigraphic position is a little vague. Teale, in the *Lexicon de Stratigraphie* (Africa), describes them as follows :—

" A. D. Combe, 1926 (*Geol. Surv. Uganda, Ann. Rept. for 1925*, pp. 14–20). Formation consisting dominantly of fine to medium-grained, compact white unfossiliferous sandstones, with interbedded quartzitic types and fine compact shale-like argillaceous sandstones. Thickness approximately several thousand feet. Beds are very slightly folded and show only low angles of dip. . . . Regarded as younger than the Karagwe-Ankolean sediments to the west."

Within the sandstones Groves found detrital tourmaline and cassiterite in the heavy mineral residues. This fact supports that these rocks are post Muva-Ankolean. But the base and the sequence is unknown.

Teale, on the other hand, has worked out the main data for the Uha System, which is now regarded as being equivalent to the Bukoban. The age of the Uha System has been a matter of doubt ; it has been considered either of Karroo or of Bukoban age. At the meeting of the Conference of African Geological Surveys (1931), held at Kigoma, the discussion on this formation showed that the consensus of opinion was against a Karroo age. The matter turned on the presence of some pseudo-plant remains and certain calcareous algae resembling *Collenia*. These calcareous algae were examined by palaeontologists, who identified them as *Cryptozoon* and *Archaeozoon*, which have a time range from Pre-Cambrian to Permian, and therefore are of little value as an index to age. It is also doubtful if the so-called plant impressions are organic at all, a doubt which was expressed by the late Professor Salée.

That Teale himself was not convinced of the Karroo age of the Uha System may be gained from a perusal of the proceedings of the Kigoma Conference, for he actually agreed with Professor Salée, when he suggested that these rocks should be correlated with the Katanga System.

De la Vallée Poussin (Chief Geologist of Uruwira Goldfields), the late N. W. Eades (late member of the Tanganyika Geological Survey), and the writer have seen and studied in the field the Uruwira Quartzites and Sandstones, which are an extension of the Malagarasi Sandstones and Quartzites, and they are of an opinion that these rocks should be correlated with the Bukoban.

Further, similar rocks from other parts of East Africa fall into line with the type area of Uha. In Buanji the lower beds of chocolate-coloured shales and flags, black grits, and massive sandstones, quartzites and grits are cut by a fault so that there lacks a continuous section, but they may be correlated with beds 1 and 2 of the Uha System (*vide* Table No. 1). The upper Buanji Series include red shales with bands of quartzite and sandstones, a dolomitic limestone, more red shales with quartzite bands, a lens of conglomerate, more reddish shale with grits, overlain by silicified and dolomitic limestone and 700 feet of amygdaloidal lava. The Uha System comprises dark to olive shales at the base overlain by the Malagarasi Sandstones, basaltic lavas, a dolomitic limestone with cherts and interbedded shales at the base, overlain by Red Beds. In Kenya the Kisii Series include (1) basalts, (2) quartzites, and (3) andesites. In Ikorongo and the Ikomo-Serengeti area of eastern Musoma District there are no volcanic rocks and the sequence in the north-east suggests a three-fold division of quartzites and shales at the base, a middle series of sandstones and greenish shales, and an upper of quartzitic sandstones: the succession in the south-east comprises green greywackes, white grits, and conglomerates at the base, overlain by purple quartzites and green and olive-coloured shales and sandstones.

In stratigraphic position, in lithology and general succession, and in the lack of index fossils, the Uha System may be correlated with those rocks that have been called Bukoban. Although the name Bukoban will probably have to remain designating this system, the type area should be considered to be Uha and the type sequence should be that of the Uha System as described by Teale.

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The Portencorkrie Complex of Wigtownshire

By Norman Holgate

INTRODUCTION

THE Portencorkrie igneous complex, a trapezoidal area of plutonic rocks intrusive into Silurian sediments, is situated in the Rhinns district of Wigtownshire some sixteen miles south of Stranraer and about four miles north-west of the Mull of Galloway. It appears on the Geological Survey (Scotland) 1-inch Sheet 1, and lies within the Ordnance Survey 6-inch quarter-sheets Wigtownshire 33 S.W. and 37 N.W. To the north and south the igneous margin can be followed with fair accuracy, while to the east the boundary is obscured by drift. Westwards, the rocks pass beneath the Irish Sea.

The complex was referred to by Teall (1899) in a general consideration of the Galloway " Granites ". His description gives a very fair idea of the variation met with in the Portencorkrie complex, although it appears that his suggestion that the most basic member of the complex is enstatite-bearing must be given a free interpretation. Since Teall's note appeared, no further work on the complex appears to have been published, although it is known that preliminary studies have been made by other petrologists.

FIELD RELATIONS AND TOPOGRAPHY OF THE COMPLEX

The Portencorkrie complex is intrusive into grits, sandstones and siltstones of Silurian age. Argillaceous types are represented in one or two localities, as at the exposures N. and S.E. of Auchneight, while conglomeratic bands appear near the igneous margin N. of Dunman. Elsewhere on the S. side of the complex the rocks are of sandy or silty types highly folded along N.E.–S.W. axes. The igneous margin in this region appears to be a normal igneous contact, with a general southerly inclination except in the extreme west, where it may be vertical. On the E. side of the igneous outcrop, the margin is largely obscured by glacial drift. At the extreme S.E. corner of the mass, however, it appears to be marked by a fault, which can be traced farther S.E. along a marked gully to a low " col " some 500 yards E.S.E. of Auchneight. Northwards, the line of the fault and igneous margin appears to cross Kilbuie Moss, beyond which it can be identified with a gully on the W. slopes of Slewtorran. Thence it follows a swampy hollow towards Inshanks Fell, on the S.W. side of which the fault appears to leave the igneous margin, which is henceforth an intrusive contact. The fault crosses Inshanks Fell by a clearly-marked slack trending in a north-easterly direction.

With the exception of some exposed on Inshanks Fell, the rocks on the eastern side of this marginal fault are entirely unmetamorphosed. In the quarries S. of West Muntloch are chloritic sandstones without any trace of reconstruction, although rocks at a similar distance from the igneous contact on the S. side of the mass show abundant metamorphic biotite (e.g. at the Sliddery Stone). Furthermore, in the gully E.S.E. of Auchneight, exposures on the E. side of the fault are of unaltered dark shales whereas a sandstone exposed close by, W. of the fault, is obviously indurated. It appears probable, therefore, that the eastern edge of the complex is defined by a fault of some importance, with a downthrow to the east.

Leaving the line of the fault S.W. of Inshanks Fell, the igneous boundary passes N.W. towards the road-junction at the W. angle of Inshanks Fell, whence, after a divergence to the N.E., it passes in a westerly direction along the S. slopes of Cairn Fell to Balloch, and so over Barncorkrie Moor to the sea just N. of Laggantalluch Head. At Balloch the margin is crossed by a deep gully which appears to mark a N.–S. line of faulting,

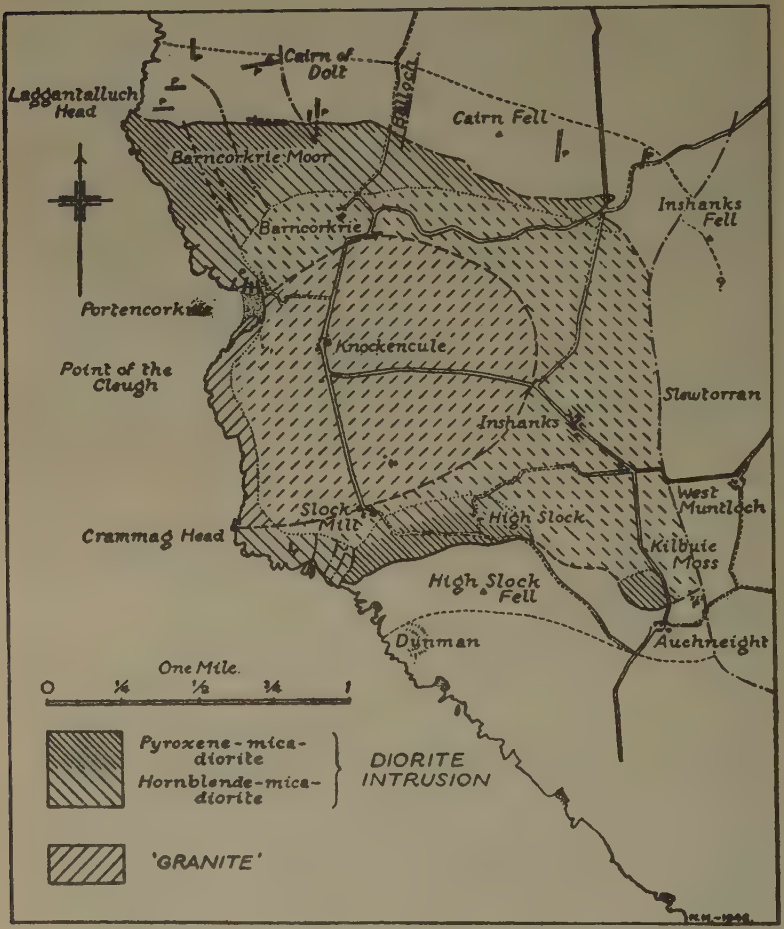

FIG. 1.—MAP OF THE PORTENCORKRIE IGNEOUS COMPLEX
The area over which the rocks are unexposed is indicated by interrupted ornament. Porphyrite dykes are labelled " P ".

although there is no obvious displacement of the igneous boundary. At other places on both Cairn Fell and Barncorkrie Moor similar but smaller features, parallel to the Balloch gully, indicate other fault- or shatter-zones. On only one of these fault-lines have displacement effects been recognized: this fault crosses the igneous margin N.N.W. of Barncorkrie farmstead, and appears to displace the line of contact. The same fracture, where it passes a short distance E. of Cairn of Dolt, clearly cuts off the E. end of an E.N.E.–W.S.W. dyke of an altered porphyrite.

The topography of the area occupied by the Portencorkrie igneous complex, in its relation to the surrounding sedimentary country, is interesting in that the igneous rocks occupy an area of lower elevation than that of the immediately surrounding sediments. To north and south, the thermally metamorphosed sedimentary rocks form strips of rough, elevated country in which the rocks are well exposed and craggy features are common. On the E. side of the complex, where the igneous margin is defined by a fault, the adjacent sediments appear to be unmetamorphosed, with the exception already noticed. This character is clearly brought out by the fact that on the E. side of the fault the higher ground is in general farther E. than the probable line of the igneous boundary, and, in view of the N.–S. strike of the folding, the presence of high ground to the E. of the marginal fault may not be dependent on the proximity of the igneous margin. The high ground adjacent to the fault is, in contrast to the country immediately to the N. and S. of the igneous area, smooth and almost devoid of exposures.

The igneous area thus forms a depressed arena bounded to N. and S. by higher ground formed by rocks of the metamorphic aureole, and to the E. by a N.–S. ridge which reflects the structures of the sediments of which it is composed. Within the arena thus defined, the more basic members of the complex occupy ground which slopes inward towards the centre of the complex. Within the area occupied by the more basic members, the ground rises in a low dome which appears to coincide with the outcrop of the acid member of the complex. This dome is crossed by numerous shallow gullies which are clearly related to the lines of faulting which have been distinguished on the higher ground of the metamorphic aureole and the igneous rocks immediately adjacent to the igneous boundary. The distribution of these features is well shown on the 6-inch maps of the area. The rocks of this central area are unexposed except where the dome has been breached by the sea and cliff exposures are available. Indeed, except for the exposures along its northern and southern margins, the only observed inland exposure of the complex as a whole is that in the farmyard at Inshanks.

THE ROCK TYPES OF THE PORTENCORKRIE IGNEOUS COMPLEX

(a) *Distribution and General Characters*

Field examination shows that while numerous and contrasting rock-types are represented, sharp mutual boundaries are rarely found. Normally the junctions between the different types are gradational, and the observed variation of the rocks only takes place over considerable distances. The nearest approach to a hiatus in the complex appears to occur near the outer margin of the central " granite " intrusion, where the rocks pass inwards from a hornblende-biotite-diorite with relict pyroxene, through a belt of increasingly acid hybrids, to the central " granite ".

The rocks of the complex have been divided into three groups : (i) the pyroxene-mica-diorite, (ii) the hornblende-mica-diorite, and (iii) the " granite ". Of these, the first two groups are component parts of an early dioritic mass which forms the greater part of the complex. The subdivision of this mass has no original petrogenetic significance, but is laid down to separate those diorites with predominant pyroxene from those in which most of the pyroxene has been replaced by members of the hornblende group. The " granite " is, in contrast, a distinct intrusion emplaced in the centre of the diorite mass, and it is believed that the boundary, as marked on the map, follows closely its outer margin.

The pyroxene-mica-diorite is characterized by the presence of a greenish augite in amounts equal to or in excess of the proportion of hornblende. The rocks are developed as a band of variable width along the northern and southern margins of the complex. They reach their greatest development at the seaward end of Barncorkrie Moor, where they occupy nearly half a mile of coastline S. from Laggantalluch Head. Eastwards the belt narrows until at about two hundred yards short of Balloch it is only about a hundred feet wide. Thence it broadens slightly and passes along the southern flanks of Cairn Fell, and is last seen in the quarries immediately E. of the Clanyard road. The pyroxene-mica-diorite also forms a continuous belt of less variable width along the southern margin from S. of Slock Mill to near Auchneight. The type exposed at Inshanks also belongs to this group.

The hornblende-mica-diorites include those dioritic types which bear subordinate pyroxene, and are characterized by abundant hornblende ; biotite, too, is much more prominent than in the pyroxene-mica-diorites. The group forms an incomplete annular outcrop between the pyroxene-mica-diorite and the central " granite " : it is incomplete from the loss of its western portion which, however, is probably completed seawards.

The central " granite " consists of a narrow but ill-defined zone of acid hybrids, continuous with the more basic hybrids included within the hornblende-mica-diorite area, surrounding an intrusion of a rock probably best described as an adamellite. It will be shown that this intrusion is younger than the surrounding diorite. The rocks of the " granite " mass are only exposed along the cliff-section between Portencorkrie and Crammag Head. The mass is shown on the accompanying map as covering an area of about a square mile extending from the road bend S. of Barncorkrie Farm in the north, to Slock Mill in the south, and from near the cottages at the road-junction N.W. of Inshanks, westwards to the coast. Since only a narrow coastal strip is exposed, the form of the outcrop has been based on indirect evidence, as follows : the veining of the diorites by granitic types ; the presence of acid types, comparable with those exposed S. of Portencorkrie, in the drift material about High Slock ; and surface features. Granitic veins are found in the pyroxene-mica-diorite immediately E. of High Slock farmstead ; a few rectilinear veins, each about an inch wide, strike N. 330° E. An exposure about 300 yards W. by N. of the same farm shows more numerous veins which bear N. 353° E. Produced towards the centre of the complex and their probable place of origin, the strikes of these veinings intersect at about a third of a mile S.E. by E. of Knockencule. A fairly obvious feature, surrounding this point and connecting with the exposed boundaries of the " granite ", defines the low dome referred to in the previous section. The periphery of this feature is shown on the map as the margin of the " granite " intrusion.

The plutonic members of the Portencorkrie complex agree in possessing a well-developed planar fluxional habit which is well seen even under the microscope. In the field it is most easily recognized by the orientation of the sieve-like biotites where these are developed, while in thin section it is equally clearly shown among the plagioclases. An attempt has been made to determine the strike of the structure at a number of localities, but the results of these measurements are not conclusive owing to the restricted exposure of the igneous rocks. In detail, the fluxional structures appear to follow the strike of the nearest boundary of the complex.

(*b*) *Petrography*

The Pyroxene-Mica-Diorites.

These are grey to dark grey, fine to medium-grained rocks of dioritic aspect, which form a more or less continuous belt marginal to the complex, particularly on its northern side. The typical diorite bears essential clinopyroxene, and may contain hypersthene in considerable amounts at localities close to the margins of the complex. The pyroxenes, more particularly the monoclinic type, tend to suffer partial amphibolization, an effect which increases as the rocks are traced inwards from the igneous margin. The marginal types, which are particularly well developed on the northern edge of the complex, show finer-grained types which, in extreme cases, pass into hypersthene porphyrites. In some places, the marginal rocks appear to have assimilated a limited amount of sedimentary material. It is interesting to note that the southern margin of the complex shows no development of marginal porphyrite types comparable with those of the northern localities.

A fairly typical example of the normal pyroxene-mica-diorite is developed near the igneous margin, a short distance N. of Auchneight. In thin section, this rock is clearly fluxional, and shows plagioclase, clinopyroxene, biotite, amphiboles, iron ores, apatite, a little quartz and potash-felspar. The plagioclase forms moderately fresh hypidiomorphic laths showing a fluxional orientation. They are twinned on the Albite, Carlsbad, and Pericline laws, and are moderately zoned from cores of an andesine-labradorite, An_{50}, to rims of a sodic andesine, An_{32}. The largest crystals show the most obvious zoning, while the smaller individuals are more uniform in composition, corresponding to the rims of the former. The pyroxene is a pale greenish augite of slightly porphyritic habit, with

Z : c = 46°, + 2V = 53° and refractive indices[1] X = 1·682, Y = 1·690, and Z = 1·703. Its usually well-formed individuals may be partly or wholly rimmed by hornblende, biotite, and chlorite, all of which appear to have grown at the expense of the augite. Biotite is fairly common, and is pleochroic with X = pale straw, Z = foxy brown ; the refractive index Y = 1·646. It shows sporadic pleochroic haloes which appear to surround small zircons. A pale green hornblende is the dominant amphibole ; it is moderately pleochroic with X = faint buff, Y = pale yellowish green, and Z = pale sea-green ; Z : c = 22°, − 2V = 76°, and refractive indices X = 1·650, Y = 1·662, and Z = 1·670. The hornblende was formed at the expense of the augite, while biotite appears to replace both of these minerals. The apparent reaction augite → green hornblende is unaccompanied by any significant separation of iron ores, whereas a reaction resulting in the replacement of augite by a confused mass of fibrous actinolitic amphibole has been accompanied by the abundant separation of magnetite granules. Two similar modes of alteration of an augite, appearing under comparable circumstances, have

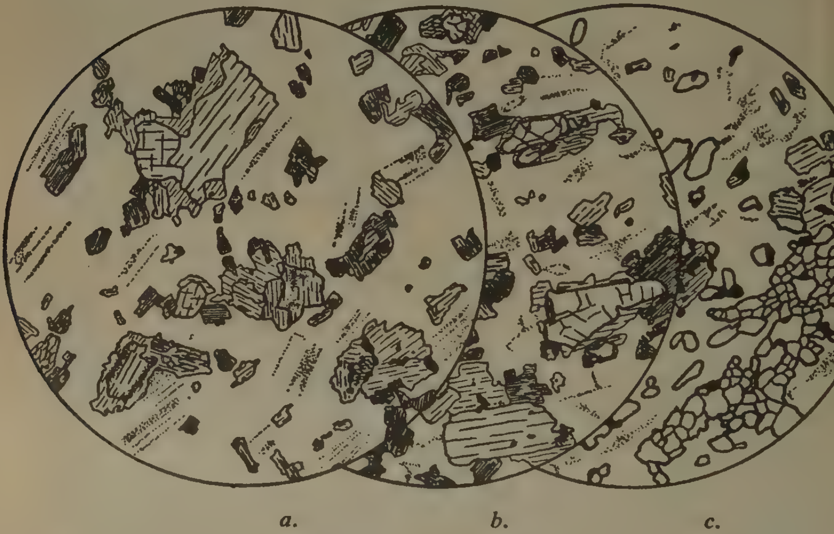

FIG. 2.—(*a*) Pyroxene-mica-diorite, N. of Auchneight. × 15. Showing augite in the early stages of conversion to hornblende and biotite. The fluxional texture of the rock is indicated by the partly-altered plagioclases (stippled).

(*b*) Marginal pyroxene-mica-diorite with early hypersthene : from Barncorkrie Moor. × 15. This rock is rather richer in hornblende and biotite than is usual in the marginal types.

(*c*) Pyroxene-mica-diorite with xenolithic patches of granular hypersthene : from Barncorkrie Moor. × 15.

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[1] All refractive indices given ± 0.003.

already been recorded from the "gabbro" of the Stanner-Hanter district, Radnorshire (Holgate and Hallowes, 1941, p. 252). The two modes of amphibolization are frequently associated in basic types bearing augite. A rather strongly-coloured chlorite may also replace augite in the Auchneight rock. Accessories include small, colourless needles of apatite, rare interstitial pools of quartz, and small patches of clear orthoclase in contact with which the plagioclases develop finely myrmekitic borders.

Sections of otherwise similar rocks, from close to the igneous margin, show idiomorphic hypersthene in variable amounts. The hypersthene has $-2V = 63°$ and birefringence $(Z - X)$ less than 0·015, which suggests about 38 per cent. $FeSiO_3$ (Henry, 1935). It is notable that this composition is identical with that obtained for the rhombic pyroxene of the Garabal Hill pyroxene-mica-diorite (Nockolds, 1941, p. 463).

On the northern margin of the complex, the normal dioritic facies passes marginally into finer-grained porphyritic modifications, which in extreme cases pass into true porphyrites at the contact and in a small apophysis from the main mass. The exact relations of these porphyrites are often obscure owing to discontinuity of exposures, but careful examination in the field shows that they are truly marginal to the pyroxene-mica-diorite. In no locality is there any hiatus between the porphyritic margin and the main intrusion, while microscopical examination confirms the continuous gradation that unites them.

In thin section, these marginal porphyrites show obvious similarities to the more dioritic types, for it is only in the more abundant hypersthene and in the character of the groundmass that any important differences can be made out. The porphyritic pyroxenes show similar habits to those of the coarser pyroxene-mica-diorites, being porphyritic by contrast with the finer-grained groundmass of the marginal variants. In detail, the clinopyroxene is an augite identical with that of the coarser pyroxene-mica-diorites. Hypersthene, as described, is invariably present, but varies in quantity. Where very abundant, much of it is of granular habit, often forming monomineralic schlieren of xenolithic aspect. Localized patches in the coarser types show similar hypersthene, which, where abundant, again takes on a granular habit and xenolithic aspect. The presence of hypersthene of this description is regarded as indicating the assimilation of sedimentary material, although the less abundant idiomorphic hypersthene is almost certainly original and of magmatic origin.

The relations obtaining between the two pyroxenes in the marginal types are of considerable interest. Normally the bulk of the orthopyroxene occurs as distinct grains or idiomorphic prisms, although it occasionally appears as cores to the clinopyroxene, which would suggest that hypersthene was crystallizing before the augite. In one section, unquestionable augite is clearly rimmed by pleochroic hypersthene, which suggests the reverse ; viz. that the hypersthene continued to crystallize after the augites had ceased to grow. In the same thin slice, an early, idiomorphic hypersthene crystal shows rimming by later hypersthene in optical continuity, the two stages of growth being distinguished by mechanical discontinuity around the "early" core. Yet other parts of the slice show the normal order. The orthopyroxene must therefore have crystallized in two stages in this rock, an early separation of magmatic hypersthene being followed by a further separation of the mineral probably consequent on the assimilation of sedimentary material. The rock contains granulitic patches of hypersthene like those previously mentioned.

Both pyroxenes have suffered alteration in ways similar to those found in the coarser, dioritic types. The augite is sometimes rimmed by small quantities of an olive-green hornblende; the hypersthene is rarely rimmed by this hornblende, and in fact only appears to be so rimmed when in close proximity to affected clinopyroxene. More typically, it shows partial rimming and replacement by biotite with X = straw yellow and Z = orange-brown; in some sections, crystals of hypersthene may be almost entirely replaced in this way. Less commonly, the hypersthene may be partially replaced by a greenish or yellowish serpentinous mineral with associated iron ores. Porphyritic plagioclases occur in fair quantity, scattered through the rock: they appear to represent the larger plagioclases of the coarser pyroxene-mica-diorites, though in the marginal porphyrites they are more abundant, as well as more calcic. They are of hypidiomorphic habit with cores of a labradorite (An_{54} to An_{60}) and outer zones of an oligoclase-andesine (An_{30}), the intermediate zones often showing small reversals. The plagioclases of the groundmass are zoned from an andesine (An_{35}) at the cores, to an oligoclase (about An_{20}) at the rims. Types with a finer-grained groundmass, and hence more obviously porphyritic, differ only in the higher degree of zoning in the porphyritic plagioclases; the cores are of a labradorite (An_{64}) with a narrow marginal zone of an oligoclase (An_{20}). The groundmass plagioclases show fluxional orientation even more clearly than do those of the coarser types, and are similarly clouded by abundant opaque, dusty granules. Among the other minerals of the groundmass are both rhombic and monoclinic pyroxenes, apparently similar to the porphyritic elements, forming a " second generation ". Apatite is fairly constant as occasional colourless needles, and quartz appears in small interstitial pools.

A small offshoot from the main intrusion runs parallel to the edge of the latter at a locality N.W. of Barncorkrie Farm, following the strike of the sediments. The rocks of this tongue are typical of the marginal porphyrites except that one thin slice shows serpentinous pseudomorphs after olivine, small scraps of the latter mineral remaining unaltered. This suggests that although the main mass of the pyroxene-mica-diorite bears no olivine, the magma from which it arose was capable of producing modal olivine at an early stage of its crystallization.

Passing inwards from the little-altered pyroxene-mica-diorites, the rocks show a change depending on the disappearance of hypersthene, and the increase of hornblende and biotite at the expense of augite, while the plagioclases gradually become more sodic in character. Quartz increases from insignificance, and with it a little potash-felspar, although neither of these attain any considerable amount in these rocks. A typical section of these less basic pyroxene-mica-diorites shows that the plagioclases are noticeably more sodic, being zoned from an andesine (about An_{40}) in the cores, to an oligoclase (An_{20}) at the rims. The crystals are often heavily altered, especially in the cores, while dusty inclusions, apparently similar to those described by A. G. MacGregor (1931), suggest that the rocks have been subject to thermal metamorphism. Hornblende is abundant, the green type being associated with optically continuous patches of a brownish type with X = pale brownish, Y = pale brown, and Z = greenish brown. Z : c for both types is about 22°. The pyroxene, which occurs as cores to many of the hornblende individuals, appears to be identical with that of the more basic types. It is sometimes twinned on (100) and occasionally repeatedly. It is interesting to note that twinned pyroxene appears almost invariably to be replaced by similarly-twinned hornblende. Biotite is common, and appears to be somewhat darker than that of the more basic types. Quartz is common interstitially in company with small plates of orthoclase, which corrodes adjacent plagioclase with the production of myrmekite fringes. Apatite is usually of slender habit and clear, but more rarely it is in the form of stouter prisms coloured by a noticeably pleochroic pigment with (O) = amethyst blue, (E) = reddish lilac to purple, in the central parts of the crystals. These pigmented apatites are a characteristic feature of many of the intermediate types of the Portencorkrie complex and appear to be associated with the hybridization by the later " granite " magma. A little anhedral sphene accompanies patches of actinolitic material pseudomorphous after pyroxene, while zircon is present, usually in association with biotite.

A xenolithic acid vein cuts the pyroxene-mica-diorites on Barncorkrie Moor ; its xenoliths show a more complete amphibolization of their pyroxene, and a more sodic plagioclase, than the diorite remote from the vein. Biotite is more abundant, while the green hornblende typical of the neighbouring diorite is largely displaced by a brown hornblende with X = pale straw, Y = light brown, and Z = brown ; Z : c = 25°. This brown hornblende forms extensive cores to the green type.

The Hornblende-Mica-Diorites.

With the reduction of pyroxene to a subordinate position relative to green hornblende, the pyroxene-mica-diorites of the outer zone merge into the hornblende-mica-diorites. Orthopyroxene is entirely unrepresented, nor can any possible pseudomorphs after it be distinguished. A typical example comes from a locality, close to the mapped outer boundary of the group, situated to the S.W. of Slock Mill. In the hand, it shows abundant hornblende and sieve-like biotite, and has the usual fluxional texture. In thin section, it differs from the pyroxene-mica-diorites in the much smaller quantities of augite, and in its more sodic plagioclases. Plagioclase is as usual the most abundant mineral, and occurs in zoned, slightly porphyritic elements as well as the almost uniform crystals of the body of the rock. The larger, hypidiomorphic individuals are often well twinned on the Carlsbad and Albite laws, with cores of a sodic andesine (An_{32}) grading outwards to rims of a sodic oligoclase (An_{14}). The smaller plagioclases are more or less uniformly of a sodic oligoclase (An_{14}). The larger crystals tend to show clouding by minute opaque granules and rods, particularly in their cores ; their rims are unaffected, as are the smaller plagioclase individuals. The hornblende of the rock is of a pale olive-green colour, and occurs as broad rims to pyroxene relics and as separate individuals ; it is apparently identical with the green hornblende of the adjacent pyroxene-mica-diorites. Biotite is abundant, in association with the other ferromagnesian minerals and as sieve-like plates of considerable extent ; its pleochroism is X = pale straw, Z = dark orange-brown. The pyroxene, which is the usual greenish augite, occurs in small quantities as relict cores in hornblende crystals. Quartz is now common interstitially, while microperthite appears as a more important, though still subordinate, constituent, corroding adjacent plagioclase. Apatite is frequent, in stumpy, purple-pigmented prisms, some of which reach 0·23 mm. by 0·08 mm. Their pigment is markedly pleochroic, with (O) = amethyst-blue and (E) = reddish lilac ; some of the more deeply-coloured crystals are almost opaque for (O). The rock has clearly undergone some degree of hybridization by an acid magma.

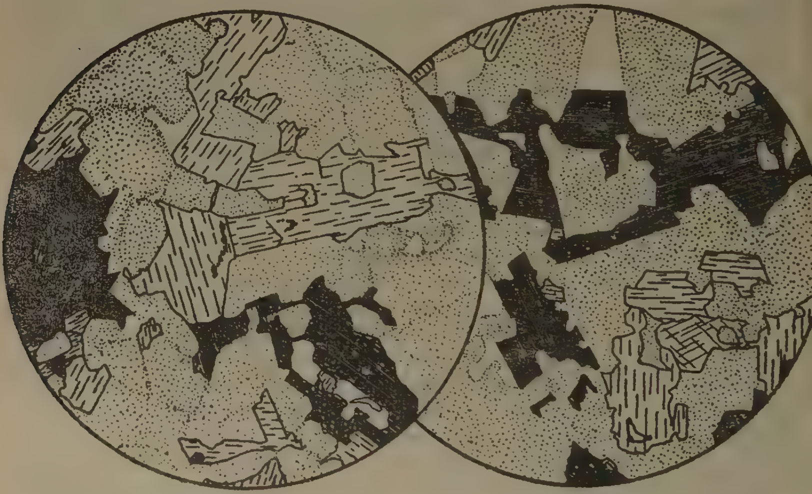

FIG. 3.—Two sections of hornblende-mica-diorites from the cliff-top S.W. of Slock Mill. × 25.

The texture, in particular the sieve-like habit of the biotite, is clearly shown. The small hexagonal sections are basal sections of the stout pigmented apatites so typical of these rocks. Pyroxene relics are rather less rare than might be gathered from these sections.

As the area occupied by the "granite" is more closely approached, the importance of the alkali-felspars increases, while pyroxene as an essential mineral disappears, although, to the last, it may persist as relics in hornblende. Hornblende is itself being displaced by the abundant biotite. An example from the N. side of Portencorkrie shows this stage. Its plagioclase shows slightly zoned crystals of larger than the average size for the rock ; these have cores of an oligoclase (An_{29}) with rims of a more sodic type (about An_{15}). The rather smaller unzoned crystals correspond to the latter composition. The cores of the larger crystals are clouded with minute opaque inclusions. Biotite is very abundant, often associated with, and apparently growing at the expense of, the hornblende of the rock. The pleochroism of the biotite is X = pale straw, Z = " dark oak " brown. The hornblende is rather like that of the previous type, agreeing in general appearance and extinction angle. Augite, apparently like that of the more basic types, occasionally appears as cores in the hornblende. Quartz is abundant interstitially, and shows undulatory extinction due to strain. Microperthite is common in association with the quartz, but also forms allotriomorphic plates. Adjacent plagioclases are, as usual, corroded with the production of myrmekite. Apatite is present both as colourless needles and as pigmented prisms. Small crystals of zircon, embedded in the ferromagnesian minerals, are accompanied by well-developed pleochroic haloes.

The " Granite " and Acid Hybrids.

These are characterized by a lower proportion of ferromagnesian minerals, among which biotite preponderates. This is obvious in the hand-specimen, where a change in the habit of the biotite is also noticeable. In the pyroxène-mica-diorites the biotites are small ; in the hornblende-mica-diorites the biotites are relatively large and have the sieve-like habit characteristic of the mineral in hybridized basic rocks ; while in the " granite " proper the biotites have reverted to a more normal idiomorphic habit, which is especially well seen in the most acid types. The " granite ", too, is coarser in texture than the diorites.

Rocks collected from the S. shore of Portencorkrie are typical of the " granite " as at present exposed. Plagioclase and microperthite are almost, if not quite, equally important, and probably justify the name adamellite for the rock. The plagioclase builds hypidiomorphic laths, most of which are quite unzoned albite-oligoclase (An_{10}), while the rare zoned individuals have rims of the same composition, their cores being of an oligoclase (about An_{25}). Some of these zoned crystals appear to have slightly dusty cores, although this is largely obscured by alteration. Microperthite forms allotriomorphic plates of considerable size ; quartz is likewise abundant, often showing signs of strain. Biotite forms idiomorphic individuals, and more rarely rims small crystals of a pale hornblende. The biotite has X = pale straw, Z = dark brown ; Y = 1·652 ; it often shows alteration to a green penninite. Granular sphene is present in small amounts.

A transition from the hornblende-mica-diorites is seen in a rock collected from the neighbourhood of the lighthouse on Crammag Head. This rock has considerable amounts of hornblende and some relict pyroxene. The plagioclase builds hypidiomorphic laths, some of which are slightly zoned and have dusty cores of an oligoclase (about An_{27}). The clear rims and unzoned crystals are of an albite-oligoclase (An_{10}). Where they come into contact with microperthite, the zoned individuals are fringed with myrmekite. The hornblende, which appears to be the same as that of the most acid type, is a pale green type with X = pale straw, Y = greenish, and Z = sage green, while $X : c = 23°$. The relation of this mineral to the green hornblende of the diorites of the complex is not clear, though some of the hornblendes of the rock bear small cores of a clinopyroxene resembling that of the diorites. Biotite is present in considerable amounts; it is usually associated with the hornblende, and often shows a tendency to a sieve-like habit. Microperthite occurs as interstitial plates affecting a monzonitic relationship with the plagioclase, while quartz is also common, and appears to be idiomorphic towards the microperthite. The accessories include apatite in colourless needles, and occasional small crystals of zircon.

XENOLITHS IN THE PLUTONIC COMPLEX

Xenoliths are rare in the Portencorkrie complex; they are almost confined to fragments of altered sediments and of occasional igneous types. The sedimentary xenoliths are almost invariably quartz-biotite-plagioclase hornfelses or similar types, which are to be met with in the marginal rocks of the diorite, on Barncorkrie Moor. Thin slices show sedimentary xenoliths clearly rounded by dissolution, while hypersthene-rich patches in these rocks may represent more highly metamorphosed xenolithic material engulfed by the diorite magma at an early stage of its cooling history.

A xenolith of particular interest was collected from the hornblende-mica-diorite exposed on the N. side of Portencorkrie. Unfortunately, it shows no clear indication of its original character, although it is almost certainly of sedimentary origin. Its present mineral composition includes plagioclase, greenish-brown biotite, zoisite, a green spinel, magnetite and possible corundum. The plagioclase, a poorly-twinned andesine (An_{35}), forms a granular groundmass in which are scattered clots of greenish-brown biotite and patches in which are associated crystal-grains of a grass-green spinel, zoisite and magnetite in a felspathic or sometimes sericitic base. Scattered in the xenolith are spongy crystals, apparently of corundum (cf. Nockolds, 1941, p. 484), which seem to be in process of corrosion with the production of biotite. Large, ill-formed crystals of epidote complete the association. The xenolith appears to be a silica-poor type comparable with the metamorphosed greywackés described from the marginal rocks of the Cairnsmore of Carsphairn complex (Deer, 1937, p. 367) except in the presence of corundum and the absence of hypersthene and cordierite in the present case. It is to be noted that no greywackés have been recognized among the neighbouring sediments.

Igneous zenoliths are exceedingly rare in the complex. Two large xenolithic blocks of an " early porphyrite " occur in the marginal diorite exposed in the northernmost of the small quarries on the E. side of the Clanyard road at the N.E. corner of the complex, while very occasional xenoliths of dioritic types are to be found in the hybridized " granite " about Crammag Head.

THERMAL METAMORPHISM OF THE PORTENCORKRIE COMPLEX

The study of the Portencorkrie complex shows that the metamorphic effects, and hence, presumably, intrusion, took place in two stages. So much is proved by the fact that while the outer, more basic, part of the complex has produced marked thermal reconstruction in the adjacent sedimentary country-rocks and on any dyke-rocks already emplaced, the inner " granite " of the complex is itself surrounded by a metamorphic aureole which shows itself most clearly in the cloudiness of the felspars, which is developed over large areas of the surrounding diorite mass. The aureole of the " granite " core of the complex cannot be recognized with certainty beyond the immediate limits of the plutonic complex.

(*a*) *Metamorphic Effects of the Diorite*

The metamorphic effects of the early diorite intrusion are probably entirely responsible for the reconstruction of the sediments within the mapped aureole. The rocks involved are predominantly silty and gritty types, with occasional shales such as are found near Auchneight. The arenaceous types lose their clastic textures as the igneous margin is approached, biotite becoming increasingly important, until the rocks attain the characters of quartz-biotite hornfelses with more or less plagioclase. Cordierite is rarely seen in these types, and pinitic pseudomorphs which may represent original cordierite are likewise far from common. A more argillaceous type of sediment close to the igneous margin is exposed on the W. side of the road immediately N. of Auchneight. The rock is a fine-grained quartz-biotite hornfels with frequent spots which appear to represent original cordierite. Cordierite also occurs in a totally-reconstructed quartz-biotite-plagioclase-cordierite hornfels collected from a locality, close to the igneous margin, some 750 yards N.W. of Barncorkrie farm. Strongly-zoned plagioclase of slightly porphyroblastic habit is fairly frequent in the thin slice ; the cores are of an andesine (An_{40}) and the rims of an oligoclase (An_{19}). Since the plagioclases of the hornfels are comparable in composition with those of the neighbouring diorite, it appears possible that the materials of the plagioclase may have been in part contributed by the dioritic magma intruded close by. No other evidence of introduction of magmatic material has, however, been observed among the sedimentary country-rocks bordering on the Portencorkrie complex. Cordierite is difficult to detect in this rock, as it is uniformly untwinned and little altered.

The " early " group of porphyrites, intrusive into the sedimentary country-rocks within the metamorphic aureole of the diorite, frequently show considerable modification of mineralogy. This statement is not intended to exclude the possibility that these effects are in part due to the " granite " of the complex, although the importance of the part played by the latter is probably small in comparison with that of the diorite. An attempt has been made to trace the progressive modification of these dykes with increasing grade of metamorphism, but unfortunately the examples available are not amenable to detailed treatment. In two cases it has been found possible to compare material from points at different distances from the igneous margin, on the same dyke. In neither case can the dyke be followed close to the diorite intrusion, nor have the unaltered rock-types been met with in the field. In other cases, the outcrop of the dyke is too restricted to show notable variation.

The most striking case of the effects of thermal metamorphism is seen in a roughly N.–S. dyke exposed in the more southerly field bounding

Cairn Fell on its eastern side. The rock was originally a medium-grained porphyrite with porphyritic pyroxene, but even at the exposures most remote from the plutonic boundary the rock shows considerable modification. The porphyritic pyroxene is a titaniferous augite with Z : c = 50°, and frequently appears as large individuals up to 3·0 mm. in length. It is fairly fresh, but may be altered marginally to a tremolitic amphibole and iron ores. The groundmass of the rock is dominated by a mesh of plagioclase laths zoned from an andesine (about An_{40}) in the cores to oligoclase (An_{30} or more sodic) at the rims. A very pale amphibole with associated sphene may be secondary after groundmass pyroxene, while epidote forms occasional small masses. A feature that is more clearly the result of thermal metamorphism is the abundant development of large poikiloblastic biotites, averaging about 3 mm. across, which envelop the groundmass minerals. The biotite has X = straw yellow, Z = dark brown : it is remarkable that, although it appears to be growing at the expense of the amphiboles, it does not appear to be replacing the pyroxene to any extent.

A section from the S. end of the same dyke shows effects due to a higher grade of thermal metamorphism. The porphyritic pyroxenes are almost completely converted to a pale green hornblende (Z : c = 23°) with associated iron ores, while, in the groundmass, similar greenish amphiboles are more definitely crystallized, and are accompanied by brownish types which show a definite crystalloblastic habit. The brownish hornblendes show colour-zoning, usually having a light brown core surrounded by a wide intermediate zone of a darker brown colour, and a narrow rim of the pale green type. The paler brown hornblende of the core has pleochroism X = pale straw, Y = olive brown, and Z = darker olive brown, while the darker zone has X = pale straw, Y = orange-brown, and Z = dark reddish-brown. Some crystals show a still darker core within the paler brown hornblende : this has X = pale straw, Y = greenish-brown, and Z = dark greenish-grey. All appear to have Z : c close to 23°. Biotite has become even more important in this more highly altered rock, as poikiloblastic plates set in the groundmass, but also as scattered crystals of a porphyroblastic habit, ranging up to 5 mm. across and 1·5 mm. thick. The accessories include sphene, iron ores, epidote, and acicular apatite. The close approach to the plutonic boundary is reflected in the development of dusty inclusions in some of the plagioclase of the rock.

A pair of thin sections from widely separated points on what may well be a single dyke, since the original identity of the rock-types concerned is almost certain, show points of interest. The dyke extends from the cliff-top N.E. of Laggantalluch Head to a fault-feature, beyond which it has not been traced, a short distance E. of Cairn of Dolt. Between these points, the continuity of the dyke appears to be interrupted by another of the N.–S. faults. A specimen from the dyke at a point S. of Cairn of Dolt shows acicular crystals and clots of amphiboles set in a ground consisting of large plates of plagioclase. Flecks and small crystals of biotite are clearly secondary. The amphiboles are two hornblendes of pale colour and of imperfectly distinguishable characters : that occurring as acicular individuals is of a light brownish-green colour with $Z : c = 23^\circ$ ca. and has $X \doteq$ pale brownish and $Y \rightarrow Z =$ light brown, while that occupying cores of amphibole clots is a pale green type with $Z : c = 23^\circ$ and pleochroic in greyish-green tints. The green hornblende appears to be replacing a pyroxene, and is surrounded by stout needles of the brownish type ; in a few cases there is an obvious intermediate zone rich in biotite. The plagioclases are fresh, strongly-zoned plates cut in all directions by hornblende needles ; the cores are of an andesine-labradorite (An_{50}) grading smoothly outwards to an oligoclase at the rims. The crystals are Albite twins, with the addition of Pericline twin-lamination in some individuals ; they show a slight dustiness which may be due to thermal metamorphism. Accessories include interstitial quartz, disseminated iron ores, a small amount of granular sphene and occasional clusters of apatite needles which show strong pigmentation of a neutral tint, with variable absorption. The other section from this dyke was taken from a locality close to Laggantalluch Head, and, while the general aspect of the rock is similar to that just described, it shows considerable differences in detail. In texture it is almost identical, but although both brown and green hornblendes are present, their relationship is changed, the brown merely forming cores to a pale green type. Sphene, in granular groups, is noticeably more abundant, probably having been ejected in the course of the conversion of brown to green hornblende. Deer (1938, p. 59) has investigated the chemistry of a similar conversion in the rocks of the Glen Tilt complex.

Biotite shows a more clearly idioblastic tendency, and is perhaps more abundant than in the Cairn of Dolt rock. Iron ores occur more plentifully and as larger individuals than the scattered granules of the previous type. The plagioclases are, however, of identical habit, and equally strongly zoned within similar limits. On the other hand, quartz is here decidedly more abundant. A further significant character of this rock is the presence of dusky apatites, like those developed in the rock from Cairn of Dolt, but in considerably greater numbers. According to Nockolds (1933), the abundance of apatite is characteristic of basic rocks which have been modified by the activity of invading acid magmas. In the present case, there is no evidence of the addition of any material other than quartz, and the volatile fluxes fixed in hornblende and apatite. This agrees with what is to be expected in view of the distance of the dyke from the margin of the diorite intrusion.

Another igneous type involved in the thermal aureole of the complex is a rather fine-grained porphyrite, originally bearing porphyritic pyroxene, although this mineral is no longer represented except by pseudomorphs. Two thin slices of this type are available, but they are derived from widely-separated sources. The less metamorphosed type is taken from an E.–W. dyke exposed some 400 yards N.E. of Laggantalluch Head, and the more altered from a xenolithic mass in the northernmost quarry E. of the Clanyard road. The types are, however, closely similar and were, in all probability, originally almost identical. Both show modification similar to that noticed in the types previously described ; the porphyritic pyroxene has been replaced by clots of biotite and pale green hornblende, the material from the xenoliths in diorite showing better crystallization in these minerals, as well as unmistakable clouding of the groundmass plagioclase by disseminated particles of iron ores.

Other dykes apparently affected by the intrusion of the plutonic complex include a N.-S. dyke intruded into the sediments at the cliff-brow due W. of Cairn of Dolt. It is an augite-biotite-diorite, but appears to be quite distinct from the marginal porphyritic variants of the diorite of the complex. The more or less completely albitized plagioclase builds indefinite laths which are poorly twinned and crowded with granular epidote, iron ores and acicular apatite. The abundant pyroxene is an augite of a faint lilac tint, forming fresh though much fractured prisms with $Z : c = 47°$ and $+ 2V$ moderate with $r > v$, distinct. Some crystals show alteration to a brownish, confused chloritic material, while in highly altered spots which are sporadically distributed in the rock the pyroxene is completely replaced by a pale green penninite. Biotite is abundant in well-formed plates and, although often associated with chloritic spots, appears itself to be uniformly unaltered. It is pleochroic with $X =$ pale straw, $Z =$ foxy red, and seems to be the result of thermal metamorphism. The more altered patches within the rock are composed of an association of calcite and chlorite spots with a colourless to faintly yellow scapolite. One such area includes a patch of brownish hornblende, while some show what appear to be embryonic crystals of biotite. The presence of scapolite suggests that the rock must have received a notable accession of volatiles, while the abundant biotite, which appears to have grown at the expense of chlorite, testifies to the activity of thermal metamorphism. No quartz has been identified in thin section.

Finally, a dyke trending N.E.–S.W. is exposed on the N. side of Cairn Fell. The rock is a spessartite with a pale brownish-green hornblende, minor quantities of paler types of amphibole, an acid plagioclase with disseminated epidote, minor biotite, and interstitial quartz. The predominant hornblende recalls that of the dyke-rock already described from near Cairn of Dolt, but the texture of the two rocks, especially as regards the felspars, is rather different, the latter mineral tending to idiomorphism in the present case. Although well beyond the metamorphic aureole of the plutonic complex, the presence of biotite and paler amphiboles in this rock may indicate some degree of metamorphism.

(*b*) *Metamorphic Effects of the Central "Granite"*

The thermal effects of the intrusion of the inner "granite" of the Portencorkrie complex are clearly developed in the earlier dioritic mass into the centre of which it has been intruded, while beyond the limits of the plutonic complex any effects are necessarily masked by the earlier metamorphism due to the diorite intrusion.

The "granite" intrusion affects the clouding of the felspars of the surrounding diorite over an annular area of considerable width, including as it does practically the whole of that intrusion. The whole of the hornblende-mica-diorite is so affected, and most of the pyroxene-mica-diorites, particularly on Barncorkrie Moor, the dustiness increasing as the "granite" is approached. Close to the latter, however, the introduction of more acid material into the rocks affected is accompanied by the restriction of the dusty areas to the cores of the larger plagioclases, the more sodic, reconstructed margins of which are clear and unclouded. As the " granite " is more closely approached and the acidity of the hybrids is further increased, the dusty cores, too, tend to disappear, although in the " granite " itself they are present in occasional xenocrysts floated off from the hybridized diorite.

Apart from the alteration produced in the diorites, little or no metamorphic activity can be definitely attributed to the central " granite " intrusion of the complex.

MINOR INTRUSIONS

A number of dykes of porphyrites and related types are intruded into the sediments surrounding the Portencorkrie complex, and a smaller number of such dykes cut the rocks of the complex itself. Some, situated within the metamorphic aureole of the latter, show obvious signs of thermal metamorphism, and are regarded as antedating the rocks of the complex. These " early porphyrites " have been fully dealt with in the previous section. In addition, there are a number of porphyrite dykes which show no clear evidence of metamorphism by the major intrusions. These, the " later porphyrites ", are of diverse characters and appear to represent the latest phase of igneous activity in the area.

The " later porphyrites " have been mapped in three localities within the outcrop of the major intrusions. Four dykes mapped on the N. shore of Portencorkrie cut the inner hybridized hornblende-mica-diorite. Another dyke cuts acid hybrids on Carrick Hill, E. of Crammag Head. A third locality, N.N.E. of Barncorkrie, shows a dyke which appears to cut the marginal pyroxene-mica-diorite as well as the adjacent sediments. Other dykes which appear to belong to this group cut metamorphosed sediments at Auchneight and on the northern parts of Barncorkrie Moor. Some of the dykes cutting the complex are of interest in that they contain xenocrysts which appear to have been derived from adjacent dioritic or granitic types.

A dark-coloured rock forming a narrow dyke on the N. shore of Portencorkrie is a hornblende-porphyrite with porphyritic plagioclase (oligoclase-andesine rimmed with albite) and green hornblende. Paler hornblendes similar to the type found in surrounding hybridized diorite occur as pseudophenocrysts. Their edges are raggy and they may enclose sphene and pyroxene, the latter indicating their provenance. Quartz grains, often compound and invariably surrounded by reaction rims of biotite and hornblende, are common. Xenocrystal biotite, with reaction rims of green hornblende, biotite and plagioclase, is occasionally met with. The groundmass consists of a green hornblende, biotite, plagioclase, and small amounts of quartz. The rock shows no sign of thermal metamorphism.

A N.–S. dyke exposed near to, and within, the diorite outcrop on Barncorkrie Moor is of light colour and might pass as a quartz-porphyry. Its large grains of quartz are, however, much rounded and may take bizarre forms, while they are rimmed by an obscure granophyric intergrowth. Crystals of biotite and of a rather peculiar greyish-green hornblende appear to be true phenocrysts ; there are also notable amounts of sphene as crystals and rounded grains. The groundmass consists of a fine-grained aggregate of felspars, quartz, and scraps of biotite, with scattered miniature euhedra of a sodic plagioclase. The quartz grains of the rock appear to be xenocrystal in origin, and not initially in true equilibrium with the rock in which they occur, although equilibrium may have been reached during the course of crystallization.

In the stream-bed at the N.E. corner of Portencorkrie is a wider dyke and subsidiary vein of a light-coloured, friable rock. It has occasional porphyritic crystals of an altered oligoclase set in a groundmass of altered plagioclase, biotite flakes, and chlorite wisps. Occasional quartz grains are surrounded by reaction-rims of badly-altered material. The dyke on Carrick Hill is of lamprophyric aspect, with a green hornblende, raggy and partly-decomposed biotite, badly-altered plagioclase, and interstitial quartz. Tremolitic clots may be pseudomorphous after a porphyritic pyroxene.

The dyke cutting the metamorphosed sediments immediately N. of Auchneight is a porphyrite with pseudomorphs of tremolite and iron ores after a porphyritic pyroxene. The groundmass consists of raggy laths of an oligoclase-andesine, green hornblende, biotite flakes, and granular sphene. Patches free from dark minerals give a variolitic aspect. The presence of biotite, which may be secondary, leads to some uncertainty as to the age of this dyke, although its similarity to a dyke cutting the hybridized diorite suggests that it is younger than the major intrusions. A dyke on the north shore of Portencorkrie is similar except in the absence of porphyritic elements ; the mass of the rock is closely similar, and has a variolitic aspect.

FORM AND PETROGENESIS OF THE COMPLEX

(*i*) *Form of the Complex*

The form of the Portencorkrie complex is rather difficult to determine on account of the low relief of the country. Near Laggantalluch Head, the surface of the diorite appears to dip away from the centre of the complex at an angle of about 30°, while similar dips probably obtain along the greater part of the northern boundary. The E. side of the complex is almost certainly faulted, while the S. edge, which is poorly exposed, may be the outcrop of a gently sloping, if rather irregular, surface. Where it reaches the sea S.E. of Crammag Head, the margin is cut off by a fault, so that no section of the contact is visible in the cliffs. Its trend immediately E. of this fault is difficult to explain except on the assumption that there the boundary is vertical or nearly so. With this exception, however, the complex appears to take the form of a broad cupola. The inner " granite " reflects the general form, although the wide zone of clouding of felspars, and of hybridization, in the surrounding diorite appears to suggest that the "granite" has a flatter form, and may underlie the diorite at no great depth to considerable distances from its boundary at the surface.

There are no indications of the presence of a floor to the complex such as is envisaged in the cases of the Cairnsmore of Carsphairn (Deer, 1935, p. 64) and Loch Doon (Gardiner and Reynolds, 1932) complexes.

(ii) *Petrogenesis*

The petrography of the Portencorkrie complex, and the associated metamorphism, show that the complex was emplaced in two stages ; first a dioritic magma was intruded, to be followed by a " granitic " magma which was emplaced approximately in the centre of the earlier diorite mass. The fact that its felspars are clouded with opaque rods and granules (MacGregor, A. G., 1931) suggests that the early diorite had become completely solid before the " granite " was emplaced.

The pyroxene-mica-diorite passes inwards through decreasingly basic types to a central " granite " mass. This seems, at first sight, to point to the conclusion that the whole of the variation within the limits of the diorite mass is to be attributed to the hybridization of the earlier rocks by the later " granite ". That this cannot be the case is well shown by a consideration of the variation found within the diorite mass. Neglecting incidental features such as the assimilation of sedimentary material, which is confined to the extreme margins of the pyroxene-mica-diorite, the variation found is as follows :—

(*a*) " Early " (magmatic) hypersthene is characteristic of the chilled marginal portions of the diorite. It becomes less common, and soon disappears, in passing a short distance inwards from the outer margin. Olivine occurs only in an apophysis on the northern margin.

(*b*) Augite is abundant in the marginal types, but shows a gradual decrease as the margins are left behind. It does not fail, however, in either of the facies of the diorite intrusion, although as the " granite " is approached it is increasingly converted to amphiboles.

(*c*) Quartz and potash-felspar are rare in the chilled marginal diorite, but show a slight increase towards the centre of the mass. In the vicinity of the " granite ", these minerals rapidly become abundant, the rock as a whole showing clear hybrid characters such as reconstructed plagioclases, abundant poikilitic biotite, and a notable increase in the amount of apatite.

The plagioclases of the diorite show even clearer evidence of this variation, if the composition of those plagioclases which show clear metamorphic clouding is considered. It can be safely assumed that such felspars must retain a composition closely similar to, if not identical with, that which they possessed prior to re-heating by the " granite ". Reconstruction, such as is seen in the hybrids immediately adjacent to the latter, involves clearing of the dusty inclusions, first from the rims and later even from the cores, of the affected plagioclase.

The variation of these unreconstructed plagioclases from various rock-types of the diorite intrusion is set out in Table 1, in which the types are arranged in order from the margin inwards. The last three rocks are two acid hybrids bearing dusty plagioclases floated off from the diorite, and the " granite " itself. The table shows that the plagioclases of the rocks of the diorite intrusion are most calcic in the marginal " porphyrites " and become increasingly sodic as the centre of the mass is approached. It also shows that the hornblende-mica-diorite has suffered the beginnings of hybridization by material derived from the " granite ", for its dusty plagioclases show clear, reconstructed rims.

TABLE 1

THE COMPOSITION OF THE PLAGIOCLASES OF THE DIORITE, ADJACENT ACID HYBRIDS, AND THE "GRANITE"

Rock.	*Composition of Plagioclases* *Cores.*	*Rims.*	*Condition of Plagioclases*
Marginal pyroxene-mica-diorite	An_{54-60}	An_{30}	Clouded throughout.
Pyroxene-mica-diorite (outer) .	An_{50}	An_{32}	Clouded throughout.
Pyroxene-mica-diorite (inner) .	An_{40}	An_{20}	Clouded throughout.
Hornblende-mica-diorite (outer)	An_{32}	An_{14}	Cloudy cores, rims clear.
Hornblende-mica-diorite (inner)	An_{29}	An_{15}	Cloudy cores, rims clear.
Acid Hybrid (outer) . .	An_{27}	An_{10}	Occasional dusty cores.
Acid Hybrid (inner) . .	An_{25}	An_{10}	Occasional dusty cores.
"Granite" (adamellite) .	An_{10}	—	Clear and unzoned.

It is not difficult to account for the observed variation within the diorite intrusion. It is reasonable to suppose that the chilled marginal types represent the composition of the dioritic magma as intruded. The mass of the intrusion, cooling slowly from without inwards, would give opportunity for the settling-out, under gravity, of the early crystals separating from the magma. This settling-out was arrested at an early stage in the marginal rocks, one of which contains olivine, and all of which bear magmatic hypersthene and porphyritic basic plagioclase. A short distance inwards from the margin sees the conspicuous decrease of rhombic pyroxene, while the larger plagioclases are more sodic in composition. In fact, the rhombic pyroxene and basic plagioclase individuals appear to have settled out before the rock had crystallized sufficiently to retard their movement under gravity. Further inwards, all of the hypersthene has disappeared ; augite is also a little less abundant. The original variation of the diorite intrusion can thus be accounted for by the crystallization-differentiation, in place, of a pyroxene-mica-diorite magma.

The status of hornblende in the less basic inner portions of the diorite intrusion is open to question. It is now an essential mineral of these rocks, but even so it appears to be present only as a product of the destruction of original pyroxene, which is almost invariably represented as relict patches in the hornblende. The rocks with predominant hornblende agree in showing evidence of hybridization, and in the same way pyroxene-mica-diorites in close proximity to acid veins show local intense amphibolization. The distribution of biotite appears to be regulated in much the same way, although the small amounts found in the most basic pyroxene-mica-diorites may be in part original. It is considered that the greater part of the biotite and of the hornblende present in the rocks of the diorite intrusion are to be attributed to the direct activity of material derived from the central "granite" intrusion.

A pigmented apatite is characteristic and common in the hornblende-mica-diorite, whereas the relatively rare apatite of the pyroxene-mica-diorite is entirely colourless, and appears to have a different status. Nockolds (1933) has remarked on the characteristic abundance of apatite in basic igneous rocks hybridized by the activity of acid magmas. The presence of abundant apatite in the hornblende-mica-diorite appears to be due to a similar cause.

The production of the rock-types lying between the marginal diorite and the central " granite " is therefore due to the interaction of two independent factors: the early diorite intrusion consisted of a rim of chilled, hypersthene-bearing pyroxene-mica-diorites which graded inwards to less basic, though still pyroxene-bearing, types produced by the crystallization-differentiation, in situ, of a pyroxene-mica-diorite magma. This initial variation was given greater apparent contrast by the hybridization of the inner parts of the diorite intrusion by material derived from the central " granite ".

The dioritic member of the Portencorkrie complex, as represented by the hypersthene-bearing marginal portions of the pyroxene-mica-diorite, resembles in mode the pyroxene-mica-diorite of the Garabal Hill-Glen Fyne complex (Nockolds, 1941). Nockolds regards the pyroxene-mica-diorite as parental to the rock-types of that complex, and suggests that it may be parental to the rock-types of the Scottish Caledonian igneous complexes as a whole. A pyroxene-diorite type from near Auchneight is slightly less basic than the marginal types; it is, in fact, an average specimen of the Portencorkrie diorite. The analysis (I, Table 2) shows it to be rather more acid than the pyroxene-mica-diorite of the Garabal Hill-Glen Fyne complex (A, Table 2). The marginal hypersthene-bearing pyroxene-mica-diorites of the Portencorkrie complex may therefore be expected to be more closely similar to the Garabal Hill rocks. Comparison in detail shows that the analysed Portencorkrie rock may be early in the liquid line of descent from the pyroxene-mica-diorite magma of Nockolds (loc. cit.). According to him, this magma typically crystallizes with plagioclase averaging between An_{40} and An_{55}, hypersthene, augite, variable amounts of olivine, prominent biotite, minor quartz, orthoclase, and accessories. The most basic types of the Portencorkrie diorite only differ in the apparent absence of olivine. Early (magmatic) hypersthene is always present in these types, and has a composition similar to that present in the Garabal Hill rocks. The presence of olivine in the rock of an apophysis of the Portencorkrie pyroxene-mica-diorite shows that the parental diorite magma was capable of precipitating olivine at an early stage.

An augite which appears to be almost identical with that of the Portencorkrie pyroxene-mica-diorite has been found by the author in the basic component of the Glen Banvie complex, Blair Atholl, Perthshire. The close similarity between these suggests a comparison with the augites of others of the Scottish Caledonian complexes. Unfortunately most of the published accounts give very little information as to the properties of the clinopyroxene. In only two cases are values of extinction angle and optic axial angle given; these are of the augites of the Criffel-Dalbeattie and Garabal Hill-Glen Fyne complexes. The " diopsidic augite " of the Criffel-Dalbeattie complex resembles the Portencorkrie and Glen Banvie augites as regards optic axial angle, but has a smaller extinction angle Z : c. Nockolds (1941, pp. 462–3) records values which

TABLE 2

ANALYSES

	I.	A.	II.	III.	B.	C.
SiO_2	57·76	54·07	58·32	67·72	70·40	67·17
TiO_2	1·24	1·30	0·88	0·48	0·68	1·31
Al_2O_3	15·17	15·36	16·02	14·74	14·89	14·60
Fe_2O_3	2·96	0·98	1·53	1·17	0·50	0·72
FeO	4·26	6·76	4·28	1·83	1·75	3·34
MnO	0·13	0·14	0·04	tr.	nil	tr.
MgO	5·14	6·44	5·04	1·67	0·83	1·84
CaO	5·30	8·09	6·79	2·39	1·61	2·32
Na_2O	4·35	3·54	3·92	4·61	3·88	3·54
K_2O	2·07	1·96	1·94	4·38	4·85	4·49
H_2O + 110° C.	0·71	0·75	0·77	0·92	0·52	0·34
H_2O – 110° C.	0·31	0·40	0·18	0·09	0·28	0·16
CO_2	n.d.	nil	nil	nil	0·03	—
P_2O_5	0·17	0·24	0·24	0·12	0·08	0 21
	99·57	100·03	99·95	100·12	100·30	100·05

I. Typical Diorite, N. of Auchneight, Portencorkrie area, Anal. N. Holgate.
A. Pyroxene-mica-diorite, Garabal Hill-Glen Fyne complex. Nockolds, S. R., *Quart. Journ. Geol. Soc.*, vol. xcvi, anal. 13, Table VII. W. H. Herdsman, analyst.
II. Hypersthene-rich marginal pyroxene-mica-diorite (contaminated by sedimentary material), Barncorkrie Moor, Portencorkrie area ; W. H. Herdsman, analyst.
III. Adamellite (" granite "), S.E. shore of Portencorkrie. W. H. Herdsman, analyst.
B. Granite, Cairnsmore of Carsphairn. Deer, W. A., *Quart. Journ. Geol. Soc.*, vol. xci (1935), p. 72, anal. 1. W. A. Deer, analyst.
C. Acid Hybrid, Cairnsmore of Carsphairn. Deer, W. A., loc. cit., anal. 3. W. A. Deer, analyst.

suggest that the comparison is unfruitful in the case of the Garabal Hill rocks. He very kindly allowed the writer to examine certain thin slices of the Garabal Hill pyroxene-mica-diorite, peridotite and pyroxenite. The similarity between the first of these and the more basic types of the Portencorkrie diorite appeared so close that the remeasurement of the optic axial angles of the augites of the Garabal Hill rocks seemed desirable. Dr. Nockolds generously consented to redetermine these optic axial angles, and the following note, due to him, embodies the revised values : " The optic axial angles of the pyroxenes were measured while I was at Manchester, using Berek's method with a simplified Universal Stage. I have now measured them directly on the full Universal Stage and have obtained values round $+ 2V = 54°$ for the pyroxene [augite] from the peridotite and pyroxenite. I also measured a few values for the pyroxene [augite] of the pyroxene-mica-diorite and these seem to come a trifle lower on the average (about 50°)." The results of the remeasurement confirm the close similarity existing between the augites of the Portencorkrie, Glen Banvie, and Garabal Hill-Glen Fyne complexes. Table 3 brings together the available data of the Scottish Caledonian igneous augites. It will be interesting to discover how far this similarity can be traced in the light of future research.

A hypersthene-rich marginal pyroxene-mica-diorite of the Portencorkrie complex has been analysed. Much of the hypersthene of the rock is granular in habit, and this appears to be in consequence of the assimilation of quartz-rich sedimentary material. The analysis (II, Table 2) shows, in spite of the more basic aspect of the rock, a higher silica percentage than that of the uncontaminated rock from near Auchneight (I, Table 2), thus supporting the view that the analysed marginal type has received a significant contribution of silica. Similar effects have been noted by Deer (1937, pp. 363–4) from the marginal rocks of the Carsphairn complex.

TABLE 3

AUGITES OF THE SCOTTISH CALEDONIAN IGNEOUS COMPLEXES

	Z : c	+ 2V	X	Y	Z
(*a*) *Criffel-Dalbeattie Complex*					
Diopsidic augite in granodiorite "G.1"	38°	52°	—	—	—
(*b*) *Garabal Hill-Glen Fyne Complex*					
Augite in augite-peridotite	46°	54°	1·680	1·686	1·705
Augite in pyroxene-mica-diorite	—	50°	—	1·687	—
(*c*) *Portencorkrie Complex*					
Augite in pyroxene-mica-diorite	46°	53°	1·682	1·690	1·703
(*d*) *Glen Banvie Complex (Perthshire)*					
Augite in modified diorite	46°	51°	1·684	1·691	1·703

Notes :—(*a*) from M. MacGregor, 1937, p. 640.
(*b*) Nockolds, 1941 ; optic axial angles revised in accordance with personal communication of 2.1.42.
(*c*) and (*d*) are new data.
All refractive indices ± ·003.

M. MacGregor (1937) accounts for the origin of the quartz-diorite of the Criffel-Dalbeattie complex by a process involving the " granitization " of the sediments surrounding the complex by emanations from the neighbouring granodiorites. It is difficult to see how such a process could have led to the production of a pyroxene-mica-diorite in the Portencorkrie area, since the surrounding sediments are, with rare exceptions, of silica-rich types which give rise, on thermal metamorphism, to quartz-biotite-plagioclase hornfelses. The xenoliths in the diorite are either definitely sedimentary or equally definitely igneous in aspect. No inclusions have been found such as might be interpreted as intermediate stages in the conversion of sedimentary material to " igneous " characters.

Nockolds, mainly from chemical data, has arrived at the conclusion that a common basic parent magma has been active in the Garabal Hill-Glen Fyne complex, the Arrochar complex (Anderson, 1935), Carn Chois (Innes, quoted by Nockolds, loc. cit., p. 497), the Etive " granite " complex (Anderson, 1937), and the Cairnsmore of Carsphairn complex (Deer, 1935). He also points out that the magma-type is abundantly represented as the pyroxene-andesite lavas of Glen Coe. In view of the close relationship of the analysed Portencorkrie pyroxene-mica-diorite to this magma-type, and of the close modal resemblance between the Portencorkrie and Garabal Hill pyroxene-mica-diorites, a resemblance which extends to the detailed mineralogy of the rocks, it appears probable that the Portencorkrie rocks belong to the same magma-series as Nockolds postulates for others of the Caledonian igneous complexes of the Scottish province.

The " granite " of the complex has also been analysed (III, Table 2). It is less acid than the central granite of the Cairnsmore of Carsphairn complex (quoted as analysis B, Table 2). An acid hybrid associated with the latter intrusion (anal. C, Table 2) shows a closely similar silica percentage, but is distinguished from the Portencorkrie adamellite by higher titania, phosphorus pentoxide, and total iron, and lower alkalies, all of which suggest that the Portencorkrie rock is a normal type rather than an acid hybrid. The origin of the adamellite magma can be accounted for by a process involving the crystallization-differentiation of a pyroxene-mica-diorite magma (see Nockolds, 1941, pp. 496–507).

The mechanism of intrusion of the Portencorkrie complex is rather difficult to visualize, particularly in the case of the diorite. The complex as a whole is poor in xenolithic material of any kind, for although there is evidence of the assimilation of sedimentary material at the northern margin of the complex, even that appears to be on a minor scale. A laccolithic form of intrusion might explain the lack of xenolithic material, but this is difficult to accept since at some parts of the diorite margin the folding of the adjacent sediments appears to strike into the igneous mass. It has been stated above that there is no evidence of the existence of a floor to the mass. The " granite " which followed the diorite may have made room for itself by disrupting the latter above and around it, the detached material being engulfed piecemeal, to sink to the bottom of the granitic magma. It is possible that this may have occurred without causing any noticeable modification of the upper part of the " granite " mass. Alternatively, the centre of the diorite mass may have subsided bodily into the " granite " magma after the manner of ring-dyke formation, the cavity over the sunken block being filled by the " granite ".

SUMMARY AND CONCLUSIONS

The Portencorkrie complex consists of an area of dioritic rocks intruded by a central " granite " (adamellite) which has extensively hybridized the adjacent diorite. The diorite consists of a single intrusion, the marginal portions of which are of a hypersthene-bearing pyroxene-mica-diorite which passes inwards to successively less basic types initially determined by the crystallization-differentiation, in situ, of a pyroxene-mica-diorite magma. The development of a marginal porphyritic facies is peculiar to the northern edge of the diorite, and this, when not modified by assimilation of sedimentary material, represents the original dioritic magma. The more basic parts of this pyroxene-mica-diorite are clearly related to the pyroxene-mica-diorites of the Garabal Hill-Glen Fyne and other Scottish igneous complexes of Caledonian age. The central " granite " also bears some similarity to the acid types of these complexes, although it is less acid than their typical granites. It was intruded soon after the consolidation of the diorite, for, while the latter has its felspars clouded as by thermal metamorphism, the " granite " shows no external chilling, nor for that matter any well-defined margin against the adjacent hybridized diorites. The mineralogical changes resulting from the hybridization of the diorite include the amphibolization of pyroxene, acidification of plagioclases, and the increase of biotite, potash-felspar, and quartz from a very subsidiary position to abundance. A pigmented apatite is characteristic of these hybrids.

The thermal metamorphism of the surrounding sediments and pre-complex dykes has been studied, and some account has been given of the dykes which are seen to cut the major intrusions.

The form of the complex has been discussed. While the upper surface appears to take the form of a flat cupola, no indication is available as to the presence, or otherwise, of a floor to the complex. The evidence does not appear to favour the assumption that the complex has a laccolithic form.

In conclusion, the author wishes to record his indebtedness to Dr. J. Phemister, who very generously waived his claim to priority at the commencement of this investigation; to Professor W. J. Pugh, for constant encouragement and for assistance in the final stages of the preparation of this paper. Also to the Victoria University of Manchester for the award of the Beyer Fellowship, during the tenure of which much of this work was carried out.

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REVIEWS

ORE DEPOSITS AS RELATED TO STRUCTURAL FEATURES. Edited by W. H. NEWHOUSE. 4to, pp. xi + 280. Princeton University Press, New Jersey, 1942. (Oxford University Press. Price 44*s.*)

All who have to do with mining metalliferous minerals know that the miner's business is to find and follow cracks and fissures in or by the sides of which the ore they want has crystallized. Cracks are incipient faults and fissures, and if they have a pattern it should be possible to relate them to local if not to regional structures and to the constitution and mechanical properties of the fractured rock. Into this fine book, " prepared under the direction of the Committee on Processes of Ore Deposition of the Division of Geology and Geography of the National Research Council, Washington, D.C.,'' during the last half-dozen years has been gathered a terse and reasoned statement of what each of some sixty individual geologists (mostly Americans) who have had " sustained and intimate contact with the ore occurrence " severally regards as the leading structural features likely to have controlled the concentration and deposition of ore minerals in the district he has dealt with. The parts which matter most to English geologists are these factual descriptions of special areas by competent observers. Facts may be " salted by interpretation " but no attempt has been made to " force a harmony which does not exist ", and the purpose of the book is to " stimulate further efforts to correlate structural features and ore occurrence ".

The opening chapter i (pp. 3–57) is at once an introduction and a summary of all that follows. In it Butler makes the interesting generalization that in tight deep-seated shear zones mineralization is by replacement and ore shoots of mined minerals are often long, whereas in the superficial region failure under stress results in brecciation, veins are infillings, zonation is usual, and specific minerals occur in narrow belts.

Lovering points out that in most districts ore-bearing solutions have emanated from a deeper-lying portion of the same magma which formed the igneous rocks near surface. The constitution of the fluids determines the type of ore, but its composition may be altered by chemical reaction with the wall rock. Place of deposition and quantity of ore depends upon precipitation gradient, which is a physical effect variable with the cross section of the channels. These regulate the amount of fluid passed through each conduit at the time when mineralizing solutions were also metallizing. This explains the importance of coarseness of the fissure filling and why openings which are effective for metasomatic replacement lie in a narrow range of capillary size.

Newhouse, chairman of the Committee and editor of the volume, admits the difficulty he has had in making any classification into which the articles by the several contributors would fit. " Complexity is probably more common than simplicity," but he has been led to adopt a view-point " emphasizing the importance of the fault or fissure in ore localization ". Attempts to distinguish ores in shear faults from those in tensional fractures are not in all respects satisfactory, but much is made of the consequences of re-fracture of fissures where they pass across from softer into harder brittle rock, and of geometrical results when uneven walls are pushed past one another whether vertically or sideways. Examples are quoted of predicted gapings which have yielded great quantities of ore. Faults of large displacement are rarely metallized—the grinding together of the walls produces gouge which is mostly impervious to the ore solutions. Comment is passed on examples of secondary tensional fractures opened across or offset from major drag surfaces, and in which the mineralization is exceptionally rich.

Next follows a tabular correlation of ore types with type of faulting, and it is shown that most hypothermal massive sulphide deposits and the mesothermal gold-quartz veins are associated with unusual faults. Mesothermal deposits other than gold quartz are found with both normal and unusual faults. Epithermal gold-silver and base metal veins are almost limited to normal faults of vertical displacement. There are many anomalous occurrences which do not fit any tightly-woven classification. There is evidence that gold-quartz veins have been introduced during intermittent faulting when each successive movement was in the same direction, and Newhouse expresses his belief that the majority of ore deposits have been introduced synchronously with certain of the stages which produced the structural features in which the ore occurs. Consideration of the relations of ore deposits to folds show that a majority of those reported on are distributed along or outside anticlines, others on the flanks, and very few centrally in the trough of synclines. Ore shoots associated with drag folds may follow the crest as saddle reefs and pitch with the axis of the fold.

Relations of ore deposits to rock type is next considered. Approximately fifty examples of favourable-unfavourable rock couples are listed by observers who report that the favourable rock has fractured without appreciable flow, and has proved strong enough for openings to be maintained. The unfavourable rocks are mostly weak and have suffered plastic deformation. Elsewhere the type of faulting has produced fractures open to ore solutions only in the less competent rocks. Tri-State zinc-lead veins, Copper Mountain (B.C.), Beatson (Alaska), and Mount Isa (Australia), are quoted as examples.

Often in standard descriptions of mining districts the emplacement of ore near contacts of physically unlike rocks is stressed. Some may have arrived by channels with or alongside the intruded magma, but more of those herein considered are in openings or zones of low compression, where surfaces of fracture bend as they cross the junction or turn along the boundary below the more resistant rock. Accepting the existence of a close relationship between intermineralization fracturing and ore shoots, the question arises how it is that the introduction of pay metal is so often very late. Choking of passageways which slowed down the rate of travel of the metal-bearing solutions and the brittleness of the first formed vein filling are accepted as factors of importance.

The proportion of ore shoots localized at junctions or intersections of veins with faults or other structures is high. Greater brecciation and more openings made at several stages of intermineralization fracturing seems a likely cause. When there was little filling or too much gouge some veins become tight and barren towards the intersections. Ore-bearing solutions are deflected by impermeable breccias and sulphide deposits are often associated with preferred fracturing along the underside. Downward moving surface waters similarly follow troughs which can only be effective where outlets are provided. Examples are quoted of these cases.

Chapter ii considers structural features associated with ore deposits of special types. It opens with a concise description of the Iron Ranges of Lake Superior by Royce. These large enrichments which are supplying much more than half the iron now manufactured for the Allied cause, have been concentrated by " downward moving oxidizing leaching solutions operating in the present erosion cycle or in any or all of many ancient erosion cycles ". The source rocks are the primeval iron carbonates, silicates, and cherts laid down " at or soon after the conclusion of great eras of vulcanism "—Middle Huronian in the Marquette, Menominee and Gogebic ranges and possibly in Vermilion and Mesabi also, though the former has been regarded as Keewatin, and the latter with Cuyuna may be later and of Upper Huronian age. There has been folding at each stage of pre-Cambrian interformational unconformities, and in later Huronian time dykes and sheets were injected, and all these have played their part in directing the concentration waters to the troughs. The most productive range, Mesabi, is less sharply folded than the others, and most if not all of its apparent local folds have been shown to be due to " slump " into voids produced by the underground leaching of silica.

Pyrometamorphic ore deposits are discussed in a general way by Knopf. They comprise mainly replacement deposits formed in a limestone environment. Their bulging away from the silicate side is explained by reactivity of carbonates in neutralizing solutions which were acid when they left the magma. It is concluded that the valuable metals of the pyrometamorphic deposits quoted, even when garnet and other high-temperature minerals are characteristic of the gangue, are of hydrothermal origin and that fault fracturing and brecciation have conditioned the access of ore-bearing solutions which travel along fissures, sometimes some hundreds of yards outwards from the igneous rock. Harrison Schmitt provides illustration of this from the Central Mining district of New Mexico, Lovering from the Front Range, Colorado, where shattering determined the emplacement of some later intrusives about which reopened cracks in the final stages were filled with metal. Singewald notes that mineralized areas in the Alma District, Colorado, have been determined by solutions rising along reversed faults and spreading to replace limestone in an intersecting belt of maximum stress. Hawley deals with mines in the Rouyn-Harricanaw belt of N.W. Quebec, where free gold came late along fractures, crush zones, or schist planes into earlier deposited vein material, and its localization is dependent upon what openings were available at the critical time, believed to be before solidification of the underlying magma was complete. At Siscoe the workings are in a small " granodiorite " stock which has been albitized and elsewhere crushed to a chloritic schist, and there is tourmaline in the intersecting quartz veins which also have been crushed. The ore bodies of McWatters gold deposit near Noranda occur within thick beds of conglomerate among tuffs along the crest of a minor anticline. Quartz-tourmaline mineralization follows drag fold surfaces, and minor fractures crossing these contain the gold. At the Granada mine, veins are almost confined to the conglomerates and productive only when they have been re-crushed. Bruce, reviewing mineral deposits of Thunder Bay, Ontario, concludes that though the silver veins may belong to the including diabase, the gold veins are in shear zones which show no relationship to the cooling history of neighbouring intrusions.

Chapter iii is concerned with ore deposits in massive rocks. Chromite deposits the world over are reviewed by Sampson. Rarely related to known faults, fissures, or shear zones, they are a variable lot, but all lie " within rocks that are or were rich in olivine ". Evenly scattered chromite is an accessory mineral in many ultrabasic rocks. The schlieren banded class of segregations have wide extent but no boundaries ; they grade into stratiform bands which in the highly differentiated lopolith intrusion of the Bushvelt, South Africa, the Great Dyke of Southern Rhodesia, and the Stillwater complex, Montana, are almost as persistent and well defined as sedimentary strata. " Sack form bodies," as at Selukwe, Southern Rhodesia, Skoplje, Yugoslavia, and perhaps Unst, Shetlands, may show linear arrangement within and related to the ultrabasic mass. Some of these certainly are magmatic segregations, but others just as likely hydrothermal replacements. In the Black Lake district of Quebec, according to Cooke, the lenses of chromite are linked along fissures, and the best ore occurs in serpentinized and faulted peridotite with much the same form as ordinary veins. A note transcribed from Read expresses the opinion that grains of schlieren and scattered lenses in the serpentines of Unst are magmatic segregations. Extracts from inaccessible papers by Hiessleitner and Lopéz tell that Yugoslavia and Greece have chromite deposits of all the types, that there may be some connection between chrome emplacement and serpentinization, and that some of the chromite has certainly grown in fissures. This whole article by Sampson is most informative.

Of the ore deposits associated with faults, fissures, and shear zones transgressing massive rocks, Chuquicamata (Antofogasta, Chile) summarized by Lopéz is taken first. The mineralized rock is a wedge of fractured granodiorite with a leucogranitic core lying " between a fault zone (at the west) and a slightly altered shear zone (at the east) ". Shear zone and tension fractures have been related to a horizontal ellipse of strain. It is thought that the western fissure tapped the magmatic reservoir. The Robinson (Ely) mining district of eastern Nevada, another of the world's leading copper producers, is dealt with by Pennebaker. Late movements have broken a curving fold which was already cut into blocks by transverse faults. Two groups of monzonite-porphyry had been intruded before the mineralization, which is mainly where late movements have shattered the earlier " ore porphyry ". It is thought that tectonic movement, not cooling, is responsible for the shattering. Solutions brought in quartz, orthoclase, and sericite along with the pyrite and chalcopyrite to fill the cracks. There is some sporadic mineralization alongside older fault zones in the adjoining sediments. Veins belonging to the porphyry belt inside but not genetically related to the surrounding batholith carry mineralization in the Boise Basin, Idaho. As described by Anderson they are concentrated in and near two loci where dykes of several ages change direction, and the country rock is shattered. The composite mineral fillings of the lodes which follow or cut obliquely across later rhyolite dykes have been brecciated, and gold is the latest mineral of a second stage. " Renewed movements during mineralization have been largely responsible for the distribution of the ore-shoots." Tin deposits of Llallagua, Bolivia, according to Turneaure have been found in a swarm of more than a thousand narrow veins and stringers crossing and near the margin of a mile-wide volcanic vent filled with brecciated quartz-porphyry. Sulphides and accessory tourmaline and wolfram accompany the cassiterite. A note by Vanderwilt tells that the Climax molybdenite deposit, Colorado, mining 12,000 tons of ore per day, produced 27 million pounds of molybdenum in 1938, and had then 140 million tons of ore in sight. The form of the deposit has been proved a pipe or chimney already 2,000 feet deep, and continuing in depth. The mineralization is all in pre-Cambrian granite or gneiss, against which are faulted shales of Upper Carboniferous age. A circular area is silicified and mineralized. Its central area 1,000–1,500 feet wide, is massive fine-grained quartz grading outwards through 300–500 feet of rock with extra quartz and secondary orthoclase to the encircling ore zone, which carries 0·5–0·3 per cent of molybdenite over a width of 100–200 feet, and fades out gradually to common rock in the surrounding 1,000–2,000 feet. The limits of the replacement quartz are well defined and uniform, they are entirely independent of recognized structural detail such as faults, fissures, contacts, or porphyry dykes. The titanium deposits of Roseland, Virginia, are described by Ross as having been introduced within a 13 mile long mass of anorthosite as a mush of rutile and ilmenite crystals and concentrated by filter press expression of the felspar in the vicinity of shear zones near the borders of the large intrusion.

Chapter iv, Ore deposits in layered rocks, Part 1, Those not related to known faults, fissures, or shear zones, begins with Gever's account of tin-bearing pegmatites in the Erongo area, S.W. Africa. The granites to which these belong appear among a complex of Archaean sediments among the roots of folded mountains, and the pegmatite dykes follow the strike and dip of schistose rocks. Some near the granite contacts are large bodies up to 50 feet thick, but most are very much narrower. Black tourmaline is abundant near the granite ; further away lithia mica and pale tourmaline accompany the cassiterite. In an essay, Landes amplifies the statement that pegmatites are rare in unmetamorphosed sediments, but are abundant in foliated rocks where structure is complex and in massive crystalline rocks whose structure has not been determined. He finds evidence that their emplacement is subject to structural control, and concludes with the statement that " the structural relationship between hydrothermal deposits within a pegmatite and the main pegmatite are probably very similar to those that exist between the main pegmatite and the parent igneous body ".

Magnetite deposits in the Adirondack area are said by Alling to occur " as pods, lenses, zones, or bands, not as veins in granites " and related rocks injected among sediments of the Grenville series. The ore bodies are either in the migmatitic zone or just below it, and like their neighbours are seamed with various pegmatites. " The structure of the one reflects the other." In many instances they behave like sediments, and performed the same structural control upon the foliation of the granite.

Chapter iv, Part 2. Ore deposits in layered rocks with faults, fissures, and shear zones, opens with a note by Bateman on the Beatson mine, which has been the second largest copper producer in Alaska. It developed a single lens-like ore-body 1,000 feet long and 400 feet thick alongside and under the Beatson fault zone. The country rock is greywacke and slate, crushed igneous rock, and a post-ore lamprophyre dyke. The ore-body was an expanded shear zone along which the metallizing solutions rose and replaced crushed rock.

A detailed account of the geology of Mount Isa, Queensland, is contributed by Blanchard. Numerous ore lenses conformable with steep dipping sediments follow shear zones in the midst of a pre-Cambrian shale belt. They are of various sizes, the largest 2,000 feet by 200 feet proved to a depth of 1,300 feet. In them silver-lead-zinc sulphides alternate with pyrite, marcasite, and pyrrhotite in narrow bands, and have replaced about half the substance of the sediment forming ore with ribboned structures. There is shearing associated with mineralization along the bedding planes, but there are also zones of shear which follow the axial planes of major folds and, dipping more steeply, cut in and out between and across the bands of sediment bounding the mineralized strips at surface or in depth. Three stages of movements are distinguished. First there were major overthrusts with horizontal displacements up to 600 ft., brecciation of competent bands and crenulation of the thinner shale beds. Breccia zones were silicified and it is they which stand as ribs across the landscape. They carry little ore. Next came a stage of more minute crushing and with it the introduction of carbonate minerals into the breccias. Some pyrite had preceded the carbonates, but mostly the sulphide ores came with crenulation of the thinner banded shale in the last stages of the thrusting, and fault displacement of ore bands is rarely more than a couple of millimetres. Finally there was cross-fracturing and a last stage of ore deposition. Former fractures were opened up, and spurts of quartz and calcite were injected. Some transecting fractures were filled with coarse deposits of pyrite and galena, and where these are numerous the average richness of the ore was greatly increased. No association of the Mount Isa ore bodies with any parent igneous magma has been established.

Reviewing conditions at Bendigo and Ballarat, Victoria, McKinstry points out that the folding which made gapes for typical saddle reef infillings is only the beginning of the story. Transgressive granites entered the district later, and these with the sediments were fractured by conjugate thrust zones, which in the mining fields follow a bed up one side of a steep fold and at the bend break acutely across to the other side. Saddle reefs are commonly under the faults at their intersection with the axial plane. Some ten sub-parallel folds about 100 yards apart with undulating crests and limbs dipping at 70° were proved productive at Bendigo. The mineralization was richest when the fault displacement is measured in inches and poor where the throw is tens of feet. At Ballarat the folding is more complex, of smaller wave length, and asymmetric; and some of the faults are continuous across from one anticline to the next.

The structure of the gold-copper-arsenic sulphide deposit of Boliden, Västerbotten, North Sweden, is illustrated by detailed plans and sections contributed by Ödman. They show " two ore bodies surrounded by an aureole of intensely sericitized and chloritized rock " in a region which is remarkable for its fresh pre-Cambrian acid—basic volcanic rocks, two miles distant from a mass of granite. The ore-bodies lack primary structure and have been interpreted as the sheared core of a steeply pitching drag fold. The arsenopyrite solutions found easy channel ways along the fold of the sericitic schist which they replaced. Irregularly scattered sulphide bodies were cut by lamprophyre dykes and traversed by gash veins filled with quartz and tourmaline before newer ore-bearing solutions replaced wall rock and older ore with great masses of pyrite.

The pyrophyllite deposits of North Carolina described by Stuckey are lenses in intensely sheared volcanic tuff in a closely folded synclinorium of Algonkian rocks. Hydrothermal mineralization followed shear zones because these were the most porous outlets in the region.

According to Brown the zinc deposits of the Edwards-Balmat district, New York, are in thick beds of altered magnesian limestone of Grenville age, and their structure may be likened to saddle reefs set on end. The mineralization follows apparent bedding which is really flow banding. During flowage brittle bands were brecciated and breccia bands govern the location of the ore shoots. Replacement is probably much later than the deformation.

The Mother Lode gold belt is reviewed by Whitehead. For 120 miles it flanks the Sierra Nevada batholith. Its most productive length is the ten miles south of the bend in Amador County in a mile-wide outcrop of isoclinally folded Upper Jurassic slate and greenstones. The quartz veins, which are notably lenticular, fill transverse reverse fault fractures. They are widest when they are refracted across junctions of slate with greenstone. Movement along them has been several times repeated, and side stringers have developed along both bedding planes and cleavage. The emplacement of the gold came late.

The fluorspar district of Illinois, Kentucky, is described by Bastin as the world's principal producing district. The walls of most of the mines are Lower Carboniferous Mississippian limestone, but mineralized veins extend across outcrops of the underlying Upper and Middle Devonian and up into the Pottsville (Upper Carboniferous). The beds are flat lying, but were gently folded to open domes broken by widely spaced persistent faults and traversed by sparsely scattered peridotite dykes in post-Pottsville pre-Cretaceous time. Mineralization is related to the sub-parallel normal faults which formed N.E.-S.W. troughs across the district. There are also short cross faults which complicate the pattern. " The fluorspar veins cut indiscriminately sandstone, shale, and limestone beds " and have sharp walls. They have the general appearance of fissure fillings, but their principal interest " lies in the clear evidence they afford of deposition mainly by replacement ". The evidence quoted is persistence of relics of stylolitic partings through the ore, the ragged corroded outlines of included limestone fragments, and the rhythmic banding of the ore itself.

The unique copper deposits of Kennecott, Alaska, described by Bateman, have yielded half a million tons of copper and eight million ounces of silver during the last thirty years. These, the largest of all known deposits of chalcocite occur near the base of a massive group of Upper Trias dolomite and limestone on the flank of a broad anticline whose core is basalt lava flows, also of Triassic age. Steep fissures are the dominant localizers of the ore within the favourable beds of dolomite. Their displacement is parallel to the dip, and they bottom on " flats " or bedding faults some little way above the greenstone. They are widest near this flat and, with some expansions where there are other bedding joints and brecciated beds, taper out upwards. The Bonanza-Mother Lode vein has been proved 4,400 feet long down dip and to have a maximum height of 400 feet across the strata, but mostly the height is less. Sixteen such veins have been mined in the district. They are largely replacement lodes ordinarily from 3–15 feet wide, but greatly enlarged even to 120 feet at base or along side joints and fissures in favourable beds. Stockwork replacements with interlacing threads of sulphide or carbonate occur along fracture zones or envelope massive sulphide veins. The source of the copper-bearing solutions remains uncertain.

Gold deposits of Porcupine, Ontario, which have produced near a million ounces of the metal each year for twenty years, and whose yield is still increasing, are reviewed by Hurst. They are at the western end of a 250 mile long infolded remnant of ancient lavas and sediment surrounded by batholithic masses of granite. Shear zones early developed have been repeatedly opened up along minor folds which flank the pitching synclinorium. Fracturing and mineralization follow these where changes of lithology across them are most abrupt, especially in the neighbourhood of the somewhat newer quartz-porphyry intrusions. Carbonate mineralization preceded quartz-tourmaline veins which are followed by quartz ankerite with a complex mineral assemblage, and it is these last fillings of reopened fractures which carry most of the gold.

Complex conditions in the Leadville District, Colorado, are summarized by Loughlin and Behre. The distribution of the ore bodies was by faults and fissures that tapped a source beneath one or other of the monzonitic stocks. The replacement deposits in dolomite are pyritic and zinc lead ores with little silver ; by contrast the veins in siliceous rocks, although some contain local shoots of lead and zinc, have been mainly valuable for their gold and silver.

Ore deposits in the Tri-State Zinc and Lead District (Picher, Oklahoma) are described by Fowler. They have yielded $850,000,000 worth of ore since 1916, all from some 300 feet of measures in the Boone formation of Lower Carboniferous age which, once all limestones, has been mostly altered to dolomite, " cotton rock " and chert. The stratigraphy has been worked out in detail and its simple sub-surface geometry is recorded by contours at 50 feet intervals over scores of square miles and at 5 feet intervals within several mining properties. Throughout the district the ore bodies are located only within zones of pre-mineral deformation. The major concentrations are combinations of fissure and bedded types in " intensely shattered shear zones contiguous to deformed strata that have opened up along the bedding planes and stylolitic partings ". The description " intensely shattered shear zones" applied to measures no more disturbed than strata in the neighbouring oil fields seems anomalous.

Noteworthy in Rove's account of the Bisbee District, Arizona, is the record of outliers which are sunken blocks many acres in extent " slumped " or let down where the oxidation of great masses of pyrite has provided acid, which locally has dissolved unfractured limestone. At Quartz Hill, near Divide, Montana, according to Taylor, there is freibergite (silver tetrahedrite) in fissures in crystalline limestone only where these end off against an overlying bed of shale.

Notes on the silver-pitchblende deposits near Great Bear Lake, N.W.T., are contributed by Kidd. He points out that the central core of Echo Bay is a line of granodiorite and diorite stocks whose aureole for half a mile around has affected old sediments and volcanic rocks, which have large masses of younger granite to the east and south of them. All these are cut by a gently dipping diabase dyke 200 feet thick. Large tension faults older than the granodiorite cross the general strike of the sediments, and stockworks with pyrometamorphic minerals are developed among them. Within the aureole all rocks are hard and brittle. Three main fractures and shear zones, in which quartz veins carry the pitchblende with haematite-cobalt-nickel minerals and native bismuth, cross them obliquely. The mineralization which brought in silver minerals, manganese carbonate, and chalcedonic quartz, with an extensive suite of copper, cobalt, nickel, and bismuth, is later than these.

Mark, Faulkner and Graton, revising earlier reports on the copper-silver ore bodies at Morococha, Peru, emphasize that after the San Francisco quartz monzonite decarbonated its contact zone, millions of tons of pure limestone just outside were converted to anhydrite and gypsum and adjoining dolomites to serpentine, and these they regard as hydrothermal outliers of the pyrometamorphic zone. Into the contact zone and through it then came new minor tongues and chimneys of a related monzonite from which important volumes of new hot solutions were expelled. Oxide and silicated minerals within the main aureole were little affected, but where a tongue reached the sulphate solution cavities were formed and when walls of these collapsed a considerable volume of rock was converted into the open textured breccia for which these mines are famous. The solutions responsible for such channelling and brecciation prepared the pathways for mineralization which was supplied later from a deeper source.

The Cobalt, Ontario, silver field has already yielded 430 million ounces of silver along with much cobalt and arsenic, all from narrow veins a few inches to a few feet wide, close spaced, but rarely so much as 300 feet in depth. Most of the country rock is late pre-Cambrian tillite, arkose, or greywacke close to the junction with the overlying thick sill of Nipissing diabase, into which some of the veins extend a little way. Moore emphasizes that though the silver may belong to the Nipissing diabase magma the mineralization is much younger than the sill, and seems to have been fed by way of thrust plane channels from below. Faulting on a large scale followed the solidification of the sill and though there was little primary deposition of metal along the major thrusts they were effective in dividing the country into blocks, the cross fractures within which are richly mineralized. In several of the mines veins in branch faults, themselves showing little or no displacement, have been followed into major faults.

The one contribution to this volume from an English school is the summary account of Rio Tinto, Spain, by David Williams. For nearly a century some three square miles of ground at Rio Tinto has supplied the pyrite for half the world, and cupriferous deposits which were worked before the Roman occupation are not exhausted yet. The mining ground is part of a latitudinal Hercynian fold made up of rolling Visean slates with interbedded quartzites along whose strike large sills or dykes of porphyry have been intruded. The walls of the more important igneous masses transgress both bedding planes and the steep " flow-cleavage " and diverging downwards may join up underground with other sills. The core of each large mass of porphyry has remained massive, but towards the margins they become increasingly fissile partly by shearing and development of cleavage, but also by the opening up of flow structure. Some of the massive porphyry is coarsely shattered, and the infilling of cracks and spaces in the breccia with sulphides has converted enormous volumes of it into stockworks. Ore bodies may be solid sulphide ore in slate, contact bodies between slate and porphyry, or ill-bounded stockworks entirely in porphyry. Boundaries are always sharp where the country rock is fissile. About the sulphide masses the porphyry is always sericitized or chloritized and some of the slate is converted into jasper. The ores are classed as mesothermal—formed at a temperature below 300° C. and it is thought that the metallizing fluids were separated from the magma during the cooling of the porphyry. The fluids followed those shrunken cracks and fissures which were not accommodated by slipping along new or old schistosity, and most material was replaced where they were dammed against impervious slates. The primary sulphides in order of crystallization are pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, tetrahedrite, but sulphides other than pyrite rarely contribute so much as 5 per cent to the bulk of rock.

The symposium concludes with a short chapter vi, in which Fairbairn, under the heading Structural Petrology applied to Ore Deposits, suggests that grain orientation determined by use of the universal stage can be " an important preliminary step " in unravelling structure in mining country where the rocks are massive and field evidence is poor.

Presenting this seriatim abstract of the findings by diverse experts concerning structural features which have guided the incoming of metal to so many of the most productive mining properties in the world, your reviewer would emphasize that the information summarized is neither more nor less than local earth history and therefore pure geology. It comes as a by-product of mining operations gathered by economic geologists who are taking responsibility for the expenditure of millions on the further development of ground to which their employers are looking for as many more hundreds of millions of mineral treasure as has been already won. In the past prospecting has been too much a practice of groping in the dark. If mineral emplacement is everywhere controlled by structure, as it is in the particular cases these authors have described, a full understanding of the stratigraphy and eruptive history of the rocks at each large mining camp must be a *sine qua non*, and the detailed survey of the surface geology should precede, and three dimensional exploration accompany, the exploitation of all mineral deposits, as well for economic purposes as for scientific record.

As geologists we must be grateful to the Division of Geology and Geography of the National Research Council, Washington, D.C., and especially to Professor Newhouse as editor for the Committee on Processes of Ore Deposition, for their assembling of so much authoritative information and its publication in wartime with adequate illustrations in so magnificent and readable a form.

W. G. F.

THE FLOOR OF THE OCEAN. New Light on Old Mysteries. REGINALD ALDWORTH DALY. The Page-Barbour Lectures at the University of Virginia, 1941. The University of North Carolina Press, 1942. pp. 177, 82 figures (Oxford University Press. Price 15*s*. 6*d*.).

"The investigation of the ocean's bed is still in its initial stage ; yet already the gains for science are so spectacular and so full of meaning that even a report of progress can have value." This "report" in three generously illustrated chapters is addressed to the non-geologist "in words perhaps not unbearably technical", and no one is better qualified than the author to select attractive items from the newer data and build them into a harmonious whole on the basis of a seemingly obvious hypothesis.

The first two chapters deal with the forms and mechanical conditions of the sial and sima and are mainly concerned to demonstrate the greater strength of the sub-oceanic crust and the existence of a weak world-circling layer beneath sial and sima. Daly's earth model has a grand simplicity and bears a striking likeness to one favoured in the early days of geology. A cold solid (crystalline) crust floats on a hot liquid (vitreous) layer. The crust, which is between ten and twenty miles thicker under the oceans than under the continental surfaces, has thickened during geological time with earth cooling. A multitude of facts can be fitted in with the reasonable behaviour of such a model and they are here marshalled in impressive array.

The old conception of a universal liquid in shallow depth was dropped when geophysical evidence proved high earth rigidity for a long way down. It was revived by Daly with the difference that the liquid, though at near-white-hot temperature, is on account of the great pressure considered to have the properties of glass and to be able to transmit the " S " earthquake waves and to resist the short-period tide producing stresses. There is great uncertainty as to the temperature at the depth (about fifty miles) at which the change from crystalline solid to glass is assumed to occur. Also we have no experimental data regarding the physical state and reactions of basic material at the temperatures and pressures involved. We must await further evidence—meanwhile the hypothesis stands. Some geologists favour it, some regard it as a desperate way out, some admit the weak substratum and its postulated behaviour, but are content to consider the question as to whether the material is glassy or crystalline as of academic interest only, whilst others favour a host of other hypotheses. It may be noted that the idea of a tachylyte sub-layer is now discarded. " It appears probable that glassy basalt cannot now be world-wide and continuous : that here and there, within broad segments, the ancient energy-charged layer has crystallized because of the slow cooling of our planet. The velocities of the earthquake waves at depth suggest that . . . there now exists a thick world-circling layer of vitreous non-crystallized material which is rich in the constituents of the mineral olivine " and is peridotite.

The third and longest chapter is a discussion of the nature of the continental terrace sediments beneath the shallow ocean borders and of the canyons and gullies of the continental slope. The persuasive reasonableness of the author's well-known theory of the origin of these latter features is contrasted with " the weaknesses of all the alternative explanations yet published ". Thus Professor W. H. Bucher is charged with emphasizing a possibility " in a purely speculative way and without proof ". There may be a faint echo here of the pot calling the kettle black, but it is all good legitimate fun—informative and instructive. It is disappointing that Daly does not discuss the problem of the origin of the ocean basins. He admits " the supreme puzzle, namely the concentration of the sial in the continental sectors " and states that the weak world-circling substratum " may yet give a basis for solving it " but leaves it at that—it is to be hoped for a short time only.

L. H.

SHIFTINGS OF SEA FLOORS AND COAST LINES. By N. L. BOWEN, J. A. CUSHMAN, and R. E. DICKERSON. University of Pennsylvania Press, 1941. 30 pp. with 15 figures (Oxford University Press. Price 3*s*. 6*d*.).

Under this title are collected three popular lectures delivered at the University of Pennsylvania bicentennial conference.

Delicate isostatic adjustments of the earth's crust under the weight of ice-caps imply mobility in the sub-crustal shell, while transmission of distortional earthquake shocks requires rigidity. Daly has supposed this sub-crustal layer to be of glassy basalt, fluid yet with high rigidity to forces of short period ; others have favoured a crystalline basaltic layer. Geophysical evidence does not admit of a choice between these alternatives, and indeed " it is not at present certain that a liquid under great pressure and a crystalline aggregate under similar conditions would exhibit recognizably different behaviour if the different kinds of earth stresses were applied to them ". Bowen concludes a six-page essay entitled " Physical Controls in Adjustments of the Earth's Crust " by reference to petrological evidence favouring the formation of basalt magma by a process of selective fusion of a crystalline mass, thus suggesting the existence of a crystalline sub-crustal layer, whose mobility would be due to recrystallization under stress.

The second article, by Cushman, is a note on the Atlantic cores obtained with the Piggot gun. These cores, ten to twelve feet in length, show both lithological and faunal changes. In particular, the foraminifera provide evidence for alternating warm and cold periods—four each in the cores from Bartlett Deep, north of Jamaica. Warmer intervals are marked by an abundance of pelagic foraminifera, while colder periods are marked by a dominantly benthic fauna of Arctic type. Evidence of underlying rocks is furnished by material believed to have been torn by the dredge from rock-ledges at the sides of the Georges Banks submarine canyons ; no details are given in these pages, but mollusca and foraminifera of Cretaceous age, and foraminifera of late Tertiary age were described by Stephenson and Cushman in *Bull. Geol. Soc. Amer.*, xlvii, 1936. The degree of compaction of these rocks is surely a factor to be considered in connection with the origin of submarine canyons.

The longest of the three articles is that by Dickerson on Molengraaff River, the name given to a buried channel extending from Sumatra north-east between Borneo and Indo-China towards Palawan (Philippines). The present rivers of Sumatra and Borneo are considered to be headwaters of tributaries and branches of Molengraaff River, and the drowned-stream tin deposits of the Sunda Sea, off Singkep Island, align themselves as minor tributaries. A lowering of sea-level by 300 feet (the postulated lowering on the Daly theory during maximum development of the polar ice-caps) would re-establish the greater part of Molengraaff River and, connecting Sumatra, Borneo, and Java westwards to the asiatic mainland, convert much of the South China Sea to dry land. Evidence for such connection in the distribution of living animals is briefly summarized. Distribution of the strangely static Hornbills on the Philippine Islands suggests that while Luzon was connected with Marinduque (now separated by a 40-fathom channel), Mindanao remained separate from Samar (though both are enclosed by the same 50-fathom line). Thus it seems likely that the lowering of sea-level was not less than 240 or more than 300 feet.

O. M. B. B.

GEOLOGICAL MAGAZINE

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The Yorkshire Dogger

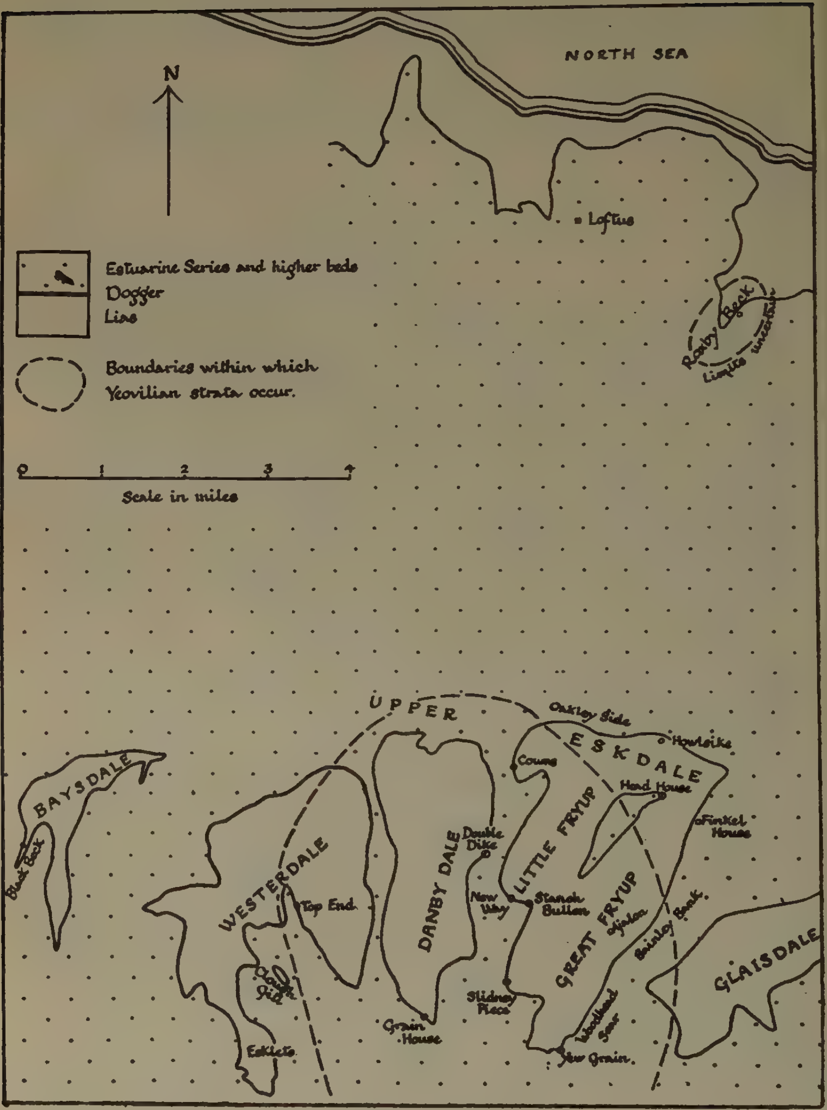
III. Upper Eskdale

By R. H. Rastall and J. E. Hemingway

THE area included in this third instalment of our work (Rastall and Hemingway, 1940 and 1941) comprises the valleys of the remaining northward flowing tributaries of the River Esk, namely the Fryups, Danby Dale, Westerdale, and Baysdale. Together with regions to the south and south-west, which will be described in later papers, this area, free from boulder clay and well dissected by streams radial to the elongated Cleveland dome, provides the finest series of inland exposures of the Lias-Oolite junction in N.E. Yorkshire. Within an area some 100 square miles in extent, no point is more than 1¼ miles from the Dogger outcrop, with the result that a three-dimensional study can be made of the several thin but highly distinctive series of successive marine deposits collectively known as the Dogger.

Originally in this area the Geological Survey grouped together as Dogger all beds between the Alum Shales of the Whitbian Upper Lias and the deltaic Lower Estuarine Series (Fox-Strangways, Reid, and Barrow, 1885). Since that time the only notable contribution has been the recognition (Macmillan, 1932) of a part of these as Yeovilian strata within an area 7 miles by 3 in the middle of the Cleveland dales region, an area which we have considerably extended. We have directed our attention chiefly to the higher beds, the Dogger in a narrower but not the narrowest sense, a group of strata long recognized as highly variable in their lithological character, so much so that field sections in two adjacent exposures may be entirely different. Since some of the rocks are low-grade ironstones, a study of the geological factors controlling their distribution is not without economic significance. A summary of the present position of Yeovilian investigation in Upper Eskdale is also included in this paper, based on Macmillan's work (Macmillan, 1932), since it provides a necessary introduction to the study of Dogger sedimentation in this area, from which it has not always been clearly differentiated.

The Dogger, in the sense in which that term will be used in this paper, i.e. post-Yeovilian and pre-Estuarine deposits, is for the most part either unfossiliferous or only sparsely so, with rare limited areas crowded with lamellibranchs of little stratigraphical value. Faunal correlation has therefore been found to be impossible, and resort has been made to the several highly distinctive lithological series, which have been found to retain their characters without variation not only within the area concerned, but throughout other districts. In other words, the complexity



TEXT-FIG. 1.—LOCALITY MAP OF UPPER ESKDALE AND ITS TRIBUTARY VALLEYS, SHOWING THE EXTENT OF THE YEOVILIAN OUTCROP.

of the exposures and their apparently rapid variation from one to the next is due not so much to lateral variation of a single bed, as was originally thought, but rather to the existence of a succession of strikingly different deposits, accompanied by considerable inter-formational erosion between successive series, or even non-deposition of one or more groups. This confuses correlation, which in the absence of fossils would not at best have been straightforward. Washout phenomena on a broad scale have also occurred in these marine sediments, with the formation of channel deposits laid down in marine embayments, or flooded river valleys.

In the limited space available it is not possible to detail all the many exposures worthy of record. Those in the valley of Great Fryup will, however, be fully described because of their complexity, while the remainder to the west will be dealt with in decreasing detail.

YEOVILIAN

Over the greater part of N.E. Yorkshire the Dogger rests non-sequentially on the Alum Shales of the lower part of the Whitbian. At Peak (Ravenscar) on the coast intermediate beds of late Whitbian and Yeovilian age have long been recognized (Buckman in Fox-Strangways and Barrow, 1915), while in the area under review and in the dales to the south similar beds have been more recently recorded in an area of some 20 square miles (Macmillan, 1932). These have now been found to attain a thickness of about 20 feet near the head of Great Fryup. They are clays and fine-grained sandstones, pale grey in colour, weathering dirty white near their base where they are distinctively lighter than the Alum Shales beneath, and are yellow limonite-stained above. They are mottled throughout, particularly in the higher coarser beds, by the casts of the marine worm *Serpula*, which during its life processes passed the bulk of this sediment through its digestive system, which silt and mud is now lighter in colour than the undigested rock.

These beds fall conveniently into a two-fold subdivision.

Serpula Series	12 feet	*dispansum* sub-zone
Striatulum Clays	10 feet	*striatulum* sub-zone

Both groups yield a lamellibranch fauna, some forms, usually *Gresslya*, being in upright position ; ammonites are frequent and belemnites are preserved only as moulds (Macmillan, 1932).

Except near the dale heads the Striatulum Clays are usually covered by hill-slip. On the other hand the Serpula Series forms a small feature of crumbling Serpula Sandstone, which as at Double Dike, Danby Dale, is sometimes capped by a thin bed of siderite-mudstone with scattered chamosite ooliths (p. 215). Phosphatized pebbles occur sporadically throughout the Serpula Series, these being mainly rolled fragments of older mudstone concretions, and they are more common at the base of the siderite mudstone. That this layer of scattered pebbles does not mark a significant time-break is indicated by the occurrence of the zone fossil *Phlyseogrammoceras dispansum*[1] in the overlying siderite-mudstone at Double Dike. At this locality, and on the east side of the rigg at Slate

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[1] This record, hitherto unpublished, was made by Mr. W. E. F. Macmillan and we are grateful to him for permission to use it.

Hills the ironstone yields a rich fauna of lamellibranchs and gastropods. This rock yields no insoluble residue after treatment with warm acid, and it clearly represents a phase of chemical deposition, at the end of *dispansum* time, which marked the culmination of steadily shallowing marine conditions.

On the western side of Great Fryup, from the Hunter's Gap bridle track to Stanch Bullen,[1] a distance of nearly a mile, the Serpula Sandstone passes rapidly upwards into a green chamosite-oolite with a chamosite cement, large micas and numerous shell fragments. This ironstone, named for convenience the Stanch Bullen Ironstone, is superficially similar to the Head House oolite (p. 217) though very different microscopically. The latter is also believed to occupy a higher stratigraphical position. While the Stanch Bullen Ironstone has not yet yielded any diagnostic fossils, it would appear to be Yeovilian in age, since the Serpula Sandstone below passes into it sharply but usually with no marked break. This lens of ironstone reaches a maximum thickness of 4 feet near the middle of its outcrop and no trace of it was found to the east or west. Its local occurrence and preservation on the western side of Great Fryup are doubtless due to the location of the maximum pre-Dogger downfolding in this area, with the consequent preservation of higher beds.

The lithological development of the part of the Yeovilian in the area under review and in the dales to the south (which may collectively be called the Cleveland Dales) is closely similar to that of the same horizons at Peak, 20 miles to the east. As far as is at present known maximum thicknesses are greater in the latter exposures, as may be seen from the following table, but there is no fundamental difference.

Blea Wyke Point, Peak	ft. in.	Cleveland Dales	ft. in.	Horizon
Yellow Beds . . .	30 0	Absent.		
Grey Beds . . .	38 6	Serpula Series .	15 0	*dispansum*
Striatulus Shales approx. .	60 0	Striatulum Clays	21 0	*striatulum*

The boundaries of the outcrop of the Yeovilian rocks have now been considerably extended. Although characteristic ammonites have not been found in all exposures, the general succession of the beds and their petrographical characters are so well marked that there can be no doubt of the correlations. They are known to occur from Westerdale in the west to Glaisdale in the east, and from Danby in upper Eskdale in the north to the limits of exposure at the south ends of Farndale and Rosedale, to the south of the area discussed in this paper (Text-figure 1). Thus Yeovilian rocks occur over an area of some 60 square miles in the Cleveland Dales. They also occur near the coast, on the south side of Roxby Beck, 6 miles north of the northern limit of the present paper. These sections have been incorrectly recorded as Dogger (Barrow, 1888, p. 42) but they show some 10 feet of fossiliferous Yeovilian with several rows of siderite-mudstone nodules underlying massive Estuarine sandstones. Whether the Roxby exposures mark the northern limit of the southern Yeovilian basin or are a part of another more northerly basin cannot be said with certainty, though the former is more likely.

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[1] Here, as elsewhere, we have followed the spelling of the 6 in. map, which does not always well reproduce the local pronunciation of the names.

Within the dales area of Cleveland the thickness of the Serpula Series decreases in all directions from the head of Great Fryup and it is finally replaced beneath the Dogger by Striatulum Clays. At still greater distances from that dale head the Dogger rests directly on Whitbian shales. Although no angular unconformity can be seen in any single section evidence such as this, wherein the Dogger rests across the basset edges of successively earlier formations, demonstrates its existence. Clearly in post- or late Yeovilian times North-East Yorkshire was folded into at least one synclinal basin, with a major N–S axis. Peneplanation followed, stripping off all post-Alum Shale (lower Whitbian) strata, but preserving Yeovilian rocks within the tectonic basin. Upon this gently folded and peneplaned Liassic surface the Dogger was deposited.[1]

THE DOGGER

In earlier papers (Rastall and Hemingway, 1940, 1941) we have defined four different developments of the Dogger in Lower Eskdale and along the Yorkshire coast. Three of these occur in the area under review. An attenuated representative of the Glaisdale Oolite Series makes a small but stratigraphically important series of exposures on Bainley Bank, Great Fryup. The Chamositic Series is widely developed, but can be dated only by reference to the Glaisdale Oolite, upon which it rests at Bainley Bank. The variable Ajalon Series here attains its maximum development, and with its variant, the Woodhead Scar Sandstone, dominates Fryup. This series also can be dated as the most recent Dogger group only by its superposition upon members of the Chamositic Series and not by diagnostic faunal evidence, which is lacking.

The Dogger sequence in Upper Eskdale and its tributary valleys is as follows [2] :—

The Ajalon Series.
The Chamositic Series.
The Glaisdale Oolite Series.

No ammonites have been found in these rocks and only the lowest group has yielded any considerable faunal assemblage. This has been pronounced by Dr. L. R. Cox to be typically Aalenian (see p. 217), and from its similarity to that of the Glaisdale Oolite in the adjacent dale, is considered to be of upper *opalinum* age. Beyond the statement that the remainder of the Dogger is post-*opalinum*, probably Upper Aalenian in age, no further definition is possible.

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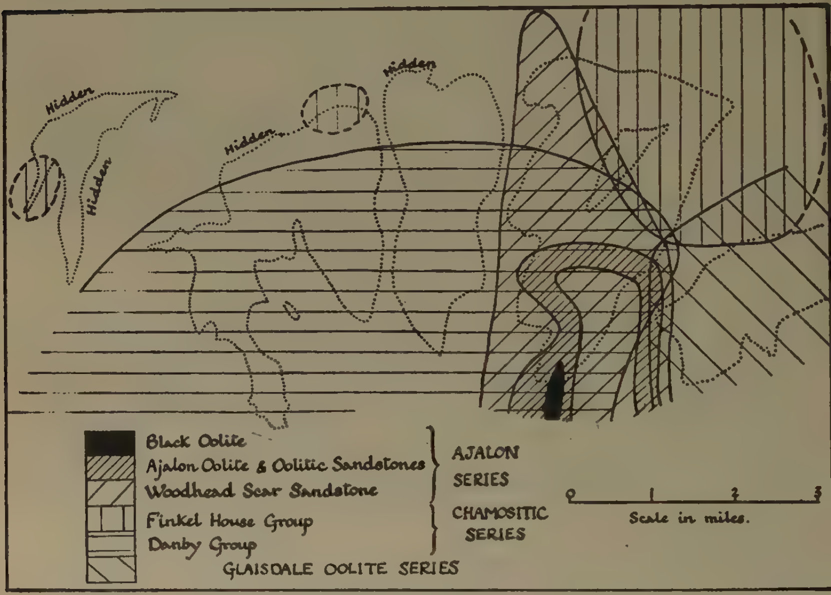
[1] Since this paper was written, Mr. Macmillan has informed us that he has found some evidence of lateral lithogical variation within the Yeovilian sub-zones in Upper Eskdale. Although this may therefore necessitate some modification in detail of the above generalizations, they will in principle remain unaltered.

[2] Such terms as " Chamositic Facies " and " Ajalon Facies " in our earlier papers are now replaced by " Chamositic Series " and " Ajalon Series " since their stratigraphical implications have become obvious.

THE CHAMOSITIC SERIES

Over a considerable part of the area under review the Dogger is represented, either entirely or in part by sandstones, oolites, and flagstones with a chamositic cement. This is unusual since the Dogger has usually a sideritic cement. These rocks form a well-defined unit in the Dogger sequence and are named the Chamositic Series. They are subdivided as follows :—



TEXT-FIG. 2.—MAP SHOWING THE DISTRIBUTION OF THE SUB-DIVISIONS OF THE DOGGER IN UPPER ESKDALE. BROKEN LINES INDICATE DOUBTFUL BOUNDARIES.

		Maximum Thickness.	
		ft.	in.
Finkel House Group .	Sandstones and oolites . . .	25	6
Danby Group . .	The Green Flags	12	0
	Black Shale	8	0
Sandstone with worm-tubes		3	6

In no one exposure can the full sequence be seen. The lowest bed occurs only at the head of Great Fryup. There it grades up into the Black Shale which in turn passes gradually into the Green Flags above. These latter two beds, together named the Danby Group, make a wide spread over the whole area and also into regions to the south and west. The Finkel House Group is more restricted and occurs to the north-east of the exposures of the lower rocks (Text-fig. 2). Its position in the sequence is fixed only at Bainley Bank where it overlies the Green Flags.

The nature of the passage from the Danby Group to the Finkel House Group cannot be determined since the junction is hidden.

It should further be noted that of the various units which make up the Chamositic Series, only the Finkel House Group is seen to rest on the Aalenian Glaisdale Oolite. Within the area under consideration the lower beds of this series are seen only to rest on Yeovilian strata of *dispansum* age, usually with an intervening pebble bed, and never upon Aalenian beds. Nevertheless on the evidence from Bainley Bank it is included with the Finkel House Group as Aalenian and as a part of the Dogger.

THE DANBY GROUP

The most widely distributed unit of the Dogger of this area, and at the same time the most constant in lithology, is the Danby Group, so called after the dale where it is best exposed. It is typically developed at the western end of Double Dike, Danby Dale, 1¾ miles south of Danby Station, where it rests on Yeovilian, thus :—

	ft.	in.
Lower Estuarine Series		
Buff, felspathic sandstones	—	
Dogger		
Danby Group		
Green Flags, speckled, micaceous and well-bedded, with some current bedding	12	0
Black Shale, well-bedded and silty towards top, with occasional *Pseudomonotis substriata*	6	0
Yeovilian		
Nodular siderite-mudstone, variably oolitic and deeply weathered ; abundant fossils preserved as casts ; scattered pebbles at base (*dispansum* sub-zone)		6
Yellow micaceous sandstone, grey towards base, with Serpula tubes in lower part (*dispansum* sub-zone)	10	0
Grey-green silty clay (*striatulum* sub-zone)	9	0
Yellow-grey shale (*striatulum* sub-zone)	—	

The Yeovilian beds have yielded a characteristic fauna, including the zone ammonite from the nodular siderite-mudstone (see p. 211). The two-fold subdivision of the Danby Series is found throughout Danby Dale, where it is fully exposed at four localities : Double Dike ; above Falcon Farm ; above Smallwoods, Danby Head ; and Grain House, Danby Head. Elsewhere in Danby and Westerdale numerous less complete exposures occur. Within these dales the Green Flags attain a maximum thickness of 12 feet, and the Black Shale 8 feet, though they are usually less.

In both the Fryup Dales one or both members of the Danby Group are frequently met with (pp. 219–222) where they form only a part of more complex Dogger sequences, which include members of other subdivisions of the Dogger. Although in such cases a part of the group has been removed by penecontemporaneous erosion, or alternatively not deposited because of local sea-floor uplift, the distinctive and constant lithology of the remainder readily admits identification.

At the head of Great Fryup is exposed a thin sandstone with shale pellets and ramifying worm tubes much larger than *Serpula* tubes and up to ¼ in. in diameter. The sandstone is brownish-green in colour, due to chamositic cement, and it passes gradually upwards into the Black Shale. This is crisp, brittle, and well-bedded, evenly laminated, with rare thin bands of barren siderite-mudstone, as at Double Dike, Danby. The shale yields only occasional *Pseudomonotis substriata*, and towards the top becomes silty and passes gradually into the Green Flags above. These are fine-grained micaceous sandstones with a chamosite cement, which weather readily to irregular flags an inch or less thick, which are themselves finely bedded, often showing small scale current-bedding. Rarely these contain fossils, as at Esklets Crag, where casts of lamellibranchs, probably *Pseudomonotis*, occur. The flags grade upwards into coarser and more blocky sandstones.

In Danby Dale, Westerdale, and Esklets the Green Flags are overlaid by deltaic Lower Estuarine Series. The junction is usually sharp, particularly where a sandstone-filled washout rests on the Green Flags, though sometimes it is less well-defined, passing by gannistroid beds or flaggy, non-chamositic sandstones into undoubted deltaic sediments. In Great and Little Fryup, however, the Danby Series, though much reduced in thickness by subsequent erosion, is overlaid by the Ajalon Series, except in the north-east where the Finkel House Group lies upon it.

THE FINKEL HOUSE GROUP

Within an area of about 3 square miles in Upper Eskdale the Dogger is represented by chamositic rocks in all respects identical with those previously described from the country around Grosmont, Egton Bridge, and the lower part of the Murk Esk valley (Rastall and Hemingway, 1941). It has not been found possible to establish the contemporaneity of these two isolated areas of similar rocks, because of the lack of faunal evidence, though such is not unlikely. This group may be described in general terms as consisting of alternations of chamositic sandstones with occasional pebbly and broken-shell beds and chamosite-oolites with a chamosite matrix.

As the type we may take the section exposed in a collapsed ironstone adit by the roadside 300 yards north of Finkel House, Great Fryup, where the series is unusually thick.

	ft.	in.
Finkel House Group		
Brown, flaggy sandstone	12	0
Siderite-mudstone		9
Chamosite-oolite	1	0
Siderite-mudstone	1	6
Chamosite-oolite	1	6
Siderite-mudstone		9
Mudstone and oolite alternating in thin beds	4	0
Hidden	2	0
Speckled chamosite-oolite with large quartz grains and pebbles at base	2	0
Whitbian		
Dark grey clay	1	0
Siderite-mudstone (impersistent)	—	
Light grey shale	2	0

From this section it is impossible to determine the field relations of this rock-group with others in the dale, but in an exposure 1½ miles to the S.S.W. a roadside quarry at Bainley Bank shows 12 feet of chamositic sandstone with siderite lenses resting on Green Flags of the Danby Group which are exposed in a roadside gutter. Further south-west a small section shows this sandstone resting on a 2 ft. bed of oolitic siderite-mudstone containing an Aalenian faunal assemblage (the Glaisdale Oolite). This establishes the position of the Finkel House Group in the Dogger sequence.

Green chamosite-oolite similar to that of the type section is exposed at Red Way, Oakley Side, west of Howlsike, and has been worked nearby at Park House for ironstone. It also occurs at the northern end of the outlier which separates Great from Little Fryup, particularly below Head House. Here an entirely incorrect interpretation of the exposures has been given by the Geological Survey (Fox-Strangways, Reid and Barrow, 1885), which in view of its possible implications must be detailed. The paragraph relating to it is as follows :—

> " The scar beneath Head House, at the entrance of Great Fryup, shows 5 feet of ferruginous Dogger on an irregular surface of white false-bedded sandstone. This sandstone, which reaches a thickness of 15 feet, is probably only an exceptional modification of the more usual ferruginous Dogger."

In point of fact this section shows only rocks of the Lower Estuarine Series, some 12 feet of normal pale yellow Estuarine sandstone, capped by a bed of ferruginous boxstones, the latter having been erroneously identified as Dogger by the surveyors. Some 25 feet lower down the hillside Dogger occurs as a fine chamosite-oolite in an abandoned ironstone adit, and in small natural exposures. It is impossible to determine the thickness of the oolitic ironstone at this point, though it must be at least 10 feet. It can be traced along the northern face of Danby Crag, but to the south it thins rapidly, since in the bridle road east of Head House Lower Estuarine Series rests directly on Whitbian Shales with only a thin intervening pebble bed.

AJALON SERIES

On Bainley Bank, on the eastern side of Great Fryup, 600 yards east of Ajalon Houses and 400 yards south-west of the most southerly exposure of the Chamositic Series, the variable oolites and oolitic sandstones (i.e. oolith-bearing sandstones) of the Ajalon Series are exposed as follows :—

	ft.	in.
Ajalon Series		
Fine purplish oolite, weathering spheroidally . . .	15	0
Glaisdale Oolite Series		
Oolitic siderite-mudstone with abundant fossils ; pebble bed at base	2	0
Yeovilian		
Striatulum Clay . . . . seen	6	0

Within the area under consideration the oolitic siderite-mudstone is unique. It is of only limited outcrop and is characterized by an extensive fauna, including several species of brachiopods, twenty-four species of lamellibranchs and four gastropods.[1] The assemblage is typically

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[1] This collection was made by Mr. W. E. F. Macmillan and identified by Dr. L. R. Cox of the British Museum (Natural History). We are grateful to Mr. Macmillan for permission to publish these records.

Aalenian, though the absence of ammonites prevents the exact determination of its horizon. From the faunal similarity it is regarded as the feather edge of the Glaisdale Oolite Series which crops out typically in the adjacent valley less than a mile to the south-east (Rastall and Hemingway, 1941).

It will be noted also that the siderite-mudstone at Bainley Bank rests on Striatulum Clay and not on Serpula Sandstone (*dispansum* age), since the exposure is located on the flanks and not near the middle of the pre-Dogger synclinal basin.

The type section of the Ajalon Series is located in a gully and crag a quarter-mile south-east of Ajalon Houses, Great Fryup, where 12 feet of dark-blue oolite passes down into a blue-grey-hearted sandstone. Like all exposures of similar ironstones and other ferruginous rocks, the section is deeply weathered, with the development of spheroidal boxstones above and a brown sandstone below.

The oolite here is identical with that already described from the Glaisdale exposures, 1,200 yards to the south and east (Rastall and Hemingway, 1941), being essentially a chamosite-oolite with a siderite matrix, and, save broken shell fragments, unfossiliferous. From the top, where it is a fairly pure oolite, it grades downwards with an increasing proportion of detrital sand grains to an ill-graded sideritic sandstone with only occasional ooliths. Its petrography is described in detail later (p. 226).

To the south-west of this section the Dogger is entirely represented by yet another rock type, a ferruginous, rather " mealy " sandstone which usually weathers to a yellow-brown or khaki colour, though it may be brick-red. It is apparently blue-hearted, with a sideritic cement, though fresh rock is rare at outcrop because of deep weathering. No fossils have been found in it. It occurs in several slips and bridle tracks to the east of Fryup Lodge, but is best exposed at Woodhead Scar, a half-mile south of Fryup Lodge, from which locality it is named the Woodhead Scar Sandstone. The section here shows :—

	ft.	in.
Lower Estuarine Series		
Massive yellow sandstone.		
Dark carbonaceous clay.		
Dogger		
Woodhead Scar Sandstone : fine-grained khaki sandstone with some current bedding. Pebble bed at base . . .	16	0
Brownish sandstone with wisps of shale. Pebbles at base up to 3 inches in length	3	6
Yeovilian		
Thin siderite-mudstone with Serpula tubes and an irregular eroded top, resting on Serpula Sandstone . . seen	12	0

The lower and thinner bed of sandstone (3 ft. 6 in.) is not again met with, and is apparently of only local development.

The Woodhead Scar Sandstone may be traced to the south-west towards Great Fryup Head where the Ajalon Facies appears again in force in a number of highly important exposures. Some of these, particularly Yew Grain, have already been discussed (Rastall and Hemingway, 1939) in connection with the Black Oolite which forms its upper part, but will be repeated here in a slightly modified form because of their importance in elucidating the sequence of the various facies.

A scar 150 yards north of Yew Grain shows the following deeply weathered section :—

	ft.	in.
Lower Estuarine Series		
Black carbonaceous clay.		
Dogger		
Ajalon Series		
Black oolite passing down through a fine-grained chamosite-oolite in a siderite matrix (Ajalon Oolite) to a fine-grained khaki sandstone (Woodhead Scar Sandstone) 3 feet from the base	12	0
Yeovilian		
Serpula Sandstone . . . seen	6	0

Again at Yew Grain is the following complete section :—

	ft.	in.
Lower Estuarine Series		
Carbonaceous shales	9	0
Dogger		
Ajalon Series		
Black oolite passing through typical grey chamosite-oolite to ill-graded sandstone with ooliths	13	0
Woodhead Scar Sandstone : fine-grained, blue-grey sandstone	3	0
Danby Group		
Green Flags		6
Black Shale, grading down to	2	0
Blue-grey sandstone, worm-chewed near base	3	6
Well marked pebble bed	—	
Yeovilian		
Siderite-mudstone, with chamosite ooliths		6
Grey Serpula Sandstone	6	0
Dark grey sandstone	6	0
Grey shale	7	0

The latter section in particular falls into a number of easily recognized subdivisions. The Yeovilian rocks are typical of much of this region and may subsequently be proved to extend further downwards than is indicated in this section. At the base of the Danby Group occurs a sandstone recognized only at the head of Great Fryup, and characterized by derived shale pellets and extensive " chewings " by a worm much larger than *Serpula* near its base. It passes up gradually into typical Black Shale, which in its turn grades into Green Flags. Only a few inches of the latter occur, the remainder having been removed by subsequent erosion. The blue-grey sandstone above is undoubtedly unweathered Woodhead Scar Sandstone. Here it is separated by a sharp break from the coarser base of the Ajalon Facies above, though 150 yards north no such junction can be defined. The Woodhead Scar Sandstone is therefore considered to be an earlier member of the Ajalon Series. Although the two are complementary in development as in this case, where the Woodhead Scar Sandstone thins to the south-west concomitant with the increase in thickness of the Ajalon Oolite, nevertheless the evidence is insufficient to admit their separation into two formations, with an intervening erosion interval with strong channelling of the earlier beds, as would then be necessary.

A series of gullies at the head of Great Fryup extending for 600 yards west of Yew Grain show the variation of the individual members of the Dogger. At Spa Dike 130 yards west of Yew Grain the section is :—

	ft.	in.
Dogger		
Ajalon Series		
Black Oolite deeply weathered	3	0
Coarse ill-graded sandstone with ooliths, shell-fragments, and pebbles up to ⅓ in. Numerous lenticular masses of siderite-mudstone. Strong current bedding from S.	12	0
Danby Group		
Green Flags		6
Black Shale, silty towards top	4	0
Sandstone with large worm tubes	3	0
Strong pebble bed.		
Yeovilian		
Sandstones and clays as at Yew Grain.		

Further exposures at George Gap and Trough Gill Beck show closely similar sections, thus :—

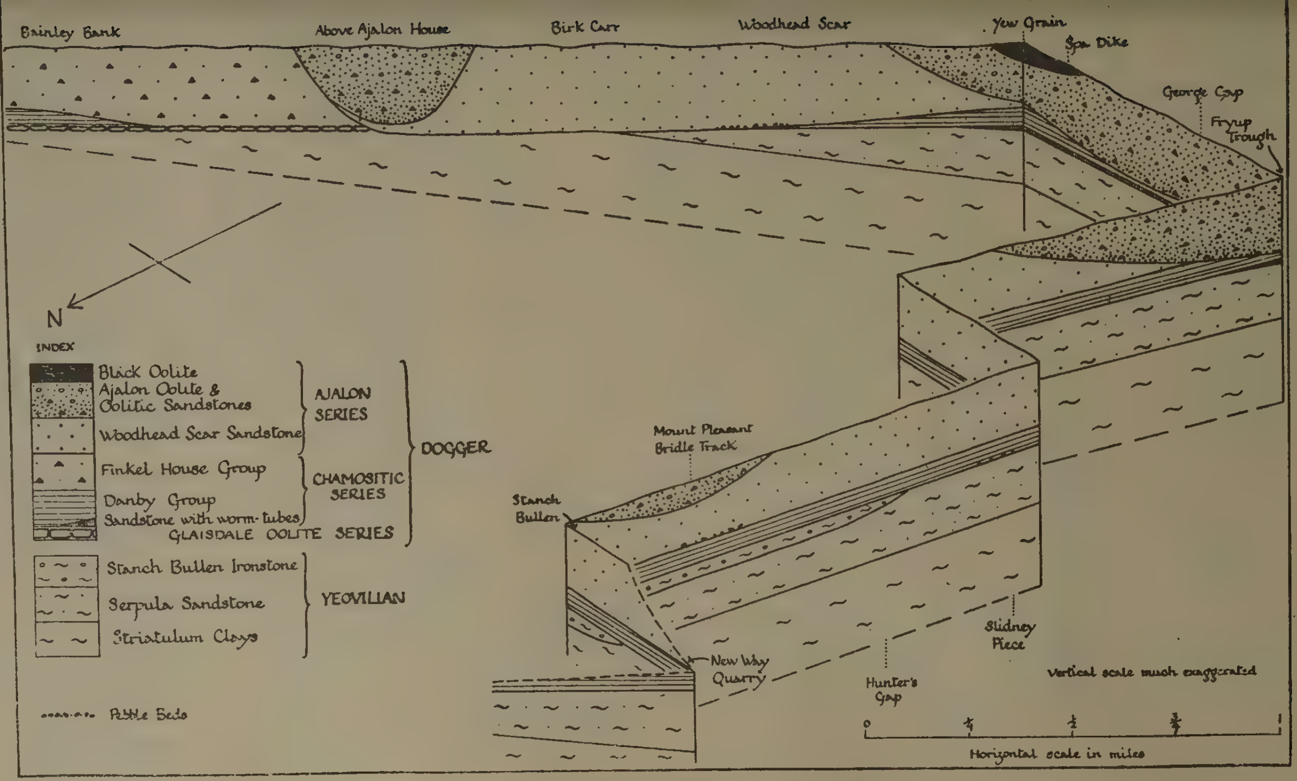
	ft.	in.
Dogger		
Ajalon Series		
Variable sandy oolites and oolitic sandstones with small pebbles throughout and lenses of siderite-mudstone	10	0
Danby Group		
Black Shale, passing down to	4	0
Worm-chewed sandstone	3	0
Yeovilian		
Serpula Sandstone approx.	10	0
Striatulum Shales	12	0

These sections together show the disappearance of the Black Oolite westwards from Yew Grain : the disappearance of the Ajalon Oolite and its replacement by ill-graded ferruginous sandstones : the disappearance of the Woodhead Scar Sandstone : the preservation of Green Flags at Yew Grain and Spa Dike, whereas elsewhere this series was eroded down to the Black Shale : the local character of the worm-chewed sandstone below the Black Shale (Text-fig. 3). Clearly this locality was one of great complexity in Dogger times.

No further exposure occurs in Fryup Head until near Slidney Piece, 1,300 yards west of Fryup Lodge, the following was measured.

	ft.	in.
Dogger		
Ajalon Series		
Woodhead Scar Sandstone	10	0
Danby Group		
Black Shale, rather silty at top	6	0
Pebble bed		—
Yeovilian		
Low-grade ironstone, poorly oolitic in a mealy siderite matrix. Vertical worm tubes and belemnite casts common	1	6
Serpula Sandstone seen	6	0

The Woodhead Scar Sandstone here varies from a speckled khaki sandstone with siderite-mudstone lenses to a blue-hearted sideritic sandstone, both with a few scattered ooliths. It is slightly current-bedded and at its base are a few scattered pebbles. It is separated from the Black Shales by a sharp, clearly-cut junction.



TEXT-FIG. 3.—Diagram showing the field relationships of the Yeovilian and the Dogger sequence at the head of Great Fryup, Upper Eskdale.

A quarter-mile to the north a bridle path to Hunters Gap exposes the Stanch Bullen ironstone (p. 212), which can be traced northwards for nearly a mile. It is exposed below Jackdaw Crag, in the track above Mount Pleasant and below the crag Stanch Bullen, but is best seen by the bridle track 200 yards south of Stanch Bullen, where its relation to the Dogger is clear.

		ft.	in.
Dogger			
Ajalon Series			
Ajalon sandstone, as at George Gap, in subsoil		—	
Woodhead Scar Sandstone		5	6
Danby Group			
Green Flags			6
Black Shales		3	0
Yeovilian			
Stanch Bullen Ironstone—Green chamosite-oolite		3	0
Serpula Sandstone	seen	8	0

Similar sections may be traced under Stanch Bullen, but at the roadstone quarry near the track New Way in Little Fryup, where the lower part of the Green Flag Series rests on Yeovilian rocks with an abnormal development of micaceous siderite-mudstones, the ironstone is not represented.

The Ajalon Series extends over a part of the Estuarine outlier between Great and Little Fryup. Here, 1,100 yards E.N.E. of Stonebeck Gate Farm a full section is exposed in a gutter, which also shows that the Stanch Bullen Ironstone does not extend so far in this direction.

		ft.	in.
Dogger			
Ajalon Series			
Woodhead Scar Sandstone		10	0
Danby Group			
Green Flags			6
Black Shale		4	0
Yeovilian			
Siderite-mudstone		1	0
Serpula Sandstone	seen	2	0

An almost identical development continues north-westwards to the Coums, one mile south of Danby Station, where at the back of a landslip brown Woodhead Scar Sandstone with thin siderite-mudstones rests on fossiliferous Yeovilian sandstones and clays. This exposure, incidentally, is one of the very few where the Lias-Oolite junction was incorrectly mapped by the original surveyors under Fox-Strangways.

Danby Dale, Westerdale, and Baysdale

In the adjacent Danby Dale the Ajalon Series is missing, and the Lower Estuarine Series rests directly on the Danby Group, as for example at Double Dike (p. 215). A group of exposures in the upper part of Danby Dale has been described by Macmillan (Macmillan, 1932). The Yeovilian Serpula Series does not occur throughout the dale. Although present about the middle of the eastern side they do not occur at the dale head to the south, where the Green Flag Series rests on *striatulum* beds. Thus at Grain Head the following section was measured.

	ft.	in.
Lower Estuarine Series		
Massive sandstone (base of washout)		
Dogger		
Danby Group		
Green Flags	2	0
Black Shale	8	0
Pebble bed	—	
Yeovilian		
Spheroidally weathering silty mudstone with *Grammoceras*, probably *G. thouarsense* (D'Orbigny), late *striatulum* age	1	3
Striatulum Clays about	20	0

The fossiliferous exposure at Piper Bridge, north of Howe Hill, Castleton, measured in detail by Tate and Blake (Tate and Blake, 1876, p. 25) is now almost entirely concealed by slipping boulder clay. From their description and faunal list the section appears similar to that at Double Dike.

Throughout a large part of Westerdale exposures are poor and infrequent. Birkfield road-metal quarry near Castleton shows 5 feet of coarse, greenish sandstone (Chamositic Series) below 15 feet of Estuarine Sandstone, while a roadside gutter at Top End, on the road from Westerdale Village to Ralph Cross, shows Green Flags resting on Striatulum Clays.

The most satisfactory exposure in Westerdale is a stream section in the small Clough Gill inlier which shows :—

	ft.	in.
Danby Group		
Green Flags	6	0
Black Shales, silty near top, with bands of siderite-mudstone	6	6
Whitbian		
Alum Shales with septaria	30	0

Slips below Esklets Crag show similar sections. These exposures near the source of the River Esk are important in that they show the Danby Group of the Dogger resting directly on Whitbian shales, with no intervening Yeovilian. The boundary of the Yeovilian basin, after its peneplanation in pre-Dogger times, can therefore be accurately fixed in this direction, between Top End, Westerdale, and Clough Gill.

In Baysdale, further west, exposures are few. Black Beck cuts a gorge through more than 20 feet of coarse greenish flags with occasional siderite lenses, many clay galls and one 18 in. bed of chamosite-oolite. This isolated exposure is allied to the Chamositic Series (Finkel House Group) and with Birkfield Quarry may be part of another small basin of chamosite deposition, though exposures are too few for this to be certain.

PETROGRAPHY

Some scores of thin sections and heavy mineral separations have been prepared from the rocks described in the preceding stratigraphical section. From these the most typical thin sections are described below, while the records of the heavy minerals present a summary of all such preparations from this area.

YEOVILIAN

The Serpula Sandstone

This fine-grained, well-graded micaceous sandstone is up to 15 feet in thickness, grey to yellow-brown in colour according to the degree of oxidation. It is equivalent in age to the Grey Beds of Blea Wyke Point (*dispansum*), with which it shows many features in common. The most notable character in nearly all localities is the great abundance of small worm-tubes, which in places form almost the whole of the rock. They are from $\frac{1}{10}$ to $\frac{1}{8}$ in. in diameter and up to 4 inches long when seen in vertical fracture, though usually they lie in all directions.

The Stanch Bullen Ironstone

This rock is a good low-grade ironstone and if of greater extent might have repaid commercial exploitation. Moderately large ooliths, averaging 0·4 mm. in diameter make up about 60 per cent of the rock. They are of flaky chamosite with chamosite nuclei, faintly brown due to weathering and limonitization at outcrop. The matrix at outcrop is now limonite after small rhombs of siderite and sideritization has also affected the ooliths which are often penetrated and partially replaced by small rhombs. Derived sand grains contribute less than 5 per cent to the rock and flakes of muscovite are common. There are no derived pebbles of phosphatized mudstone or ironstone such as are commonly found in the Aalenian ironstones above, and the phosphorus content of the rock will therefore be low.

Yeovilian Ironstones in General

Other low grade ironstones of Yeovilian age occur at Slidney Piece (p. 220), New Way quarry (p. 222), Grain Head, Danby Dale (p. 223), and elsewhere. They all contain a high proportion of quartz sand, well-graded and averaging 0·08 mm. in size and all highly corroded, often to fantastic shapes. Muscovite flakes are common. Scattered ooliths occur throughout the rock, but these are derived and are now replaced by kaolinite, though sometimes retaining the flaky form of the original chamosite. The matrix of the rock which is irregularly distributed, due in part to the worm tubes in the rock, is finely crystalline siderite and forms up to 60 per cent of the rock.

Thin beds of ironstone such as these, up to 2 feet in thickness, are fairly common in the higher parts of the *dispansum* zone. They are of no commercial interest and are more correctly described as sideritic siltstones.

Heavy Minerals

The heavy concentrates from these beds are most distinctive and extremely uniform, so as to be of diagnostic value. They are characterized by minute grain-size (maximum about 0·05 mm.), perfect grading, and a remarkably limited assemblage ; in fact the only transparent minerals are zircon, rutile, and tourmaline. Garnet, anatase, and brookite are never present. Rutile is notable for unusual types, rarely seen in the other stratigraphical divisions here described. The usual dark orange to crimson forms are rarely seen, but are replaced by pale varieties, ranging from almost colourless and primrose yellow to bright yellow or pale orange. Other colours of frequent occurrence are olive brown and olive green, while a variety showing strong pleochroism (green to purple) is by no means rare. Twins are fairly abundant (Rástall, 1939).

AALENIAN

The Danby Group

This group of rocks is of little petrological interest, though a valuable and widespread stratigraphical horizon. The flags are well-graded sandstones, the sand grains being almost entirely quartz interspersed by layers of muscovite. Ooliths are locally present, usually derived, but derived pebbles are rare. The heavy mineral assemblage is not very distinctive, characterized by moderate to large grain size, fairly good grading, limited assemblage, and scarcity of anatase though brookite is rather common. Rutile is present in the dark coloured varieties only. In the west, e.g. Westerdale, there is a little garnet.

The Finkel House Group

The dominant feature of this series is the abundant development of chamosite, largely as chamosite ooliths, but even in the sandstones the matrix is chamosite, rather than siderite, as is usual in the Dogger. The oolites have been tried for ironstone near Head House and Finkel House, Great Fryup, and along Oakley Side, near Howlsike. The workings were never extensive and were presumably abandoned because of the sandy character of the rock.

Below Head House, Great Fryup

These sediments are typical of the oolitic rocks of this series. They are somewhat flaggy and deeply oxidized, with a few white specks of decomposed felspar and small pebbles of mudstone.

Microscopic examination shows these rocks to be mainly composed of ooliths and deeply corroded, sharply angular sand grains in varying proportions in a nearly opaque limonitized matrix. The ooliths, which are dominant in most specimens, consist of fairly fresh green or pale brown chamosite with concentric structure, showing good black crosses under crossed nicols. Many have a core of flaky chamosite. The greenish-brown variety of chamosite, showing moderately high birefringence, is a common result of slight oxidation before decomposition. The sand fraction is nearly all quartz and small grains of micro-quartzite. The matrix, which is here weathered to limonite, is seen in a fresher sample from Howlsike to be blue-green chamosite. No siderite was identified with certainty.

Adit near Finkel House.

As appears from the field description (p. 216) this section shows an alternation of chamosite-oolites with sandstones with a chamosite matrix and detailed petrography concurs in assigning these rocks to the Chamositic Series. The section is important petrologically in providing a link between the oolitic development of this series, as below Head House and near Howlsike, and the arenaceous development, to be next described.

Bainley Bank Quarry

Resting upon Green Flags in their typical development is a coarse, greenish grit in parts of which occur numerous lenses of finely crystalline siderite which give a striped appearance to the rock. This is the type section of the sandy facies of the Chamositic Series.

In the slice the rock consists of a mixture of sharply angular, highly corroded quartz grains averaging about 40 per cent of the rock, with a small proportion of zircons and altered felspars, together with broken and entire chamosite ooliths (10 to 25 per cent). The matrix is chamosite as is typical of this series, but siderite crystals, usually with dark cores, are commonly scattered through the rock, particularly round the margins of the chamosite and quartz fragments. Some crystals penetrate the chamosite ooliths, while all organic fragments are replaced in siderite.

Although the siderite crystals rarely show perfect rhombic form it is not considered that they were ever rolled appreciably on the sea-floor. The process of sideritization of these rocks, which is common in many divisions of the Dogger, one of which Black has described (Black, 1938, p. 133), probably took place soon after deposition, when the sediment was attacked by carbonated solutions. The macroscopic lenses of siderite, which are very similar to " galliard " in Coal Measure sandstones, must also have originated in a similar way, by local segregation of siderite before lithification. In all siderite of penecontemporaneous origin makes up about 10 per cent of the rock.

Heavy Minerals

The heavy mineral concentrates from the oolites of these series are not very distinctive. At Head House anatase in blue pyramids is dominant, while rutile is very abundant. Brookite is rare, but a few crystals show rather abnormal optical properties, with comparatively small axial dispersion. A notable feature, however, is the presence of a small number of grains of pink garnet, a mineral of western affinities which was never seen in the more eastern chamosite pool near Egton Bridge (Rastall and Hemingway, 1941).

Concentrates from the Howlsike district show less anatase and more brookite, while those from Bainley Bank are dominated by rutile with only a little anatase.

THE AJALON SERIES

The rocks of this series vary from coarse ferruginous sandstones to sandy oolitic ironstones and black oolites. The more arenaceous facies is closely similar lithologically to the Dogger of the Yorkshire coast (Rastall and Hemingway, 1940), though in point of fact it is younger.

Gully above Ajalon House

The ironstone forming the upper few feet of this type section is a dark-coloured, heavy, coarse-grained aggregate of many constituents varying much in their relative proportions. The chief constituents are ooliths and sand-grains, but pebbles and shell-fragments are also common.

The ooliths are as a rule fairly small, less than 0·3 mm. in diameter, though the maximum seen is 0·55 mm. They consist of pale green, fresh chamosite with the usual concentric structure and flaky chamosite nucleus. The majority have sharp margins and a few are broken, though secondary sideritization is not uncommon. In such cases siderite rhombs up to 0·03 mm. long replace chamosite round the margins of the ooliths and penetrate irregularly into them. The ooliths are undoubtedly of contemporaneous origin, but must have travelled a short distance, since oolite formation would be unlikely in the sandy or pebbly environment in which they finally rested. It may be noted that methylene blue has proved particularly useful in staining the chamosite structures and picking them out from the parti-coloured mosaic.

Sand grains are very abundant in the ironstone comprising up to 40 per cent of the rock, and are chiefly quartz with some quartzite. They are badly graded and range up to 1·25 mm. in length, though they are usually much smaller. The large grains are moderately well rounded and are unaltered, while the smaller are angular and are considerably corroded. Siderite crystals penetrate deep into such grains and in some cases disintegrate them.

Well-rounded grains of isotropic phosphatized mudstone, undoubtedly derived from the Lias and up to 2 mm. in length, are common in the coarser layers. Some show recrystallization of the phosphate to felted masses of water-clear laths of apatite within the pebble, as has been already described (Rastall and Hemingway, 1939, p. 229). Other large grains of chamosite-sandstone and chamosite-oolites have an isotropic, phosphatized matrix and are clearly derived from younger Dogger deposits, having suffered phosphatization before incorporation in the sediment. The frequent fossil fragments, which usually cannot be identified, are replaced in comby siderite.

The matrix also consists of pale brown siderite, often in large plates with a somewhat radial structure suggesting sphaero-siderite. The individual crystals, up to 1·2 mm. long, show marked poikilitic structure, enclosing single or groups of ooliths or quartz grains.

The oolite maintains this character for the upper 12 feet of the section. Below this it becomes finer in grain and more uniformly graded and evidence of sideritization sets in. Near the base of the section small siderite rhombs up to 0·04 mm. long have completely replaced the original matrix and make up some 20 per cent of the rock. Whether the matrix was originally siderite or chamosite cannot be stated with certainty, though from comparison of accepted examples of the sideritization of chamosite, it would appear that the latter is more likely. Such a conclusion, if maintained, would entail a great change in the belts of deposition during Ajalon times, beginning with essentially siliceous conditions, depositing a chamosite matrix and passing subsequently into a carbonated one, when a siderite matrix was laid down and percolating carbonated water sideritized the older Ajalon sediments. At the same time it connotes some continuity with the chamosite-depositing conditions of the rock group immediately preceding it, the Chamositic Series.

Yew Grain

The Yew Grain section is important in that it shows the relationship of the Ajalon Series to the Woodhead Scar Sandstone underneath and also that the Black Oolite is merely a special development of the Ajalon Series. The Ajalon Series proper, 13 feet thick, varies from an ill-graded sideritic sandstone with few ooliths at the base, through an oolite with few sandgrains to black oolite, the petrography of which has already been described (Rastall and Hemingway, 1939, p. 225). The whole division is dark coloured and, because of the siderite matrix, of fairly high specific gravity, with occasional bands of pure siderite. The rock consists of a mixture of varying proportions of ooliths, chamosite below but kaolinitized above, ill-graded sandgrains, broken fossils including echinoderm debris, now sideritized and locally derived small pebbles and grains of phosphatized mudstone and oolites and silicified oolites. The matrix is always siderite of varying texture.

Spastolithic structure (Rastall and Hemingway, 1940, p. 265) is not common in the ooliths of the Ajalon series either at Yew Grain or in the type section above Ajalon House. It has been seen in rocks from Ajalon exposures on Bainley Bank to the north-west, suggesting that this structure is more commonly located on the flanks of Ajalon deposits rather than in the centre.

Heavy Minerals

The heavy mineral concentrate from the type section shows several very distinctive features which are of diagnostic value for this series. It is unusually large and during preparation a great quantity of black oily-looking scum separated in acid, which is characteristic. The maximum grain-size is large, and there is no grading. Besides the inevitable zircon, rutile, and tourmaline, anatase is common in blue pyramids or complex groups with no yellow tints. There is no brookite. Other minerals present in small quantities are garnet, staurolite, monazite, chloritoid, epidote, corundum, and blue amphibole. This is a distinctive assemblage which recurs again and again to the south and west, but has never been seen further east. Although the minerals in the last list are very rare they are persistent and distinctive. In rocks from this locality both pink and colourless much-etched garnet has been found.

CONDITIONS OF DEPOSITION

The sequence of events that can be traced in the Dogger of Upper Eskdale shows a series of changing conditions of deposition. The oldest unit of the Dogger, which rests unconformably on the peneplaned structural basin of Yeovilian and Whitbian shales and silty sandstones is the attenuated feather edge of the Glaisdale Oolite Series, which occurs at the eastern limit of the area here described. Whether these rocks were ever laid down further west is not known, but it seems likely that the present outcrop is near the margin of the original depositional basin. In all probability the remainder of the area was above or near sea-level at this time.

There would appear to be a definite time-break before the deposition of the succeeding Chamositic Series. This began near the head of Great Fryup where a few feet of sandstone accumulated in shallow water, as is indicated by the abundant worm tubes. Continued subsidence then effectively flooded the whole of the region during which the Black Shale was laid down in a quiet but not deep marine environment. From this conditions gradually reverted to a shallower phase when the muddy sediments grade steadily upwards into laminated but current-bedded Green Flags. In Danby and much of Westerdale this is the youngest Dogger known. The area of deposition then moved to the north-east, sandy oolites flanked by sandstones, the Finkel House Group, were deposited. A second similar region also existed to the north-west, but evidence there is less clear.

The occurrence of the black shale at the base of the Danby Group immediately above the plane of unconformity may be paralleled in the Mississippi valley where the black Noel or Eureka shale (Mississippian) rests unconformably on eroded Ordovician (Grabau, 1906). Grabau suggests that the residual soil, rich in organic carbon, which accumulated on the old peneplane surface was incorporated into the basal bed, the Eureka shale. In the case of the black shale of the Danby Group, however, it is unnecessary to invoke the incorporation of only the weathered soil, since it is likely that Liassic clays also contributed directly to its formation. It may be noted that in both the American and the Yorkshire examples of this type of unconformity, the black shale grades up into fine-grained clastics.

Profound changes both physiographic and chemical took place at the end of the deposition of the Chamositic Series. From an essentially chamosite-depositing environment the marine chemical conditions reverted to the deposition of siderite among the derived sediment, a state similar to that of the earlier Glaisdale Oolite time. The Chamositic Series mark a diminution in the acidity of the sea-water in which they were laid down, which acidity increased during the Ajalon phase when siderite was again precipitated. Further, carbonating waters from Ajalon seas percolated down into the Chamositic Series sideritizing in situ the older chamosite.

Physiographically much of Upper Eskdale was again near or above sea-level at this time in an environment where no further sediment accumulated. Over Great Fryup, however, a considerable shallow channel was eroded into the earlier Dogger, cutting through it in places. It is likely that the channel was cut sub-aerially during elevation of the region immediately before Ajalon time, and was filled with marine sediment during subsequent partial submergence similar to conditions further south-west (Black, 1934). The Woodhead Scar Sandstone was first laid down. The isolated outcrops of the oolitic ironstones and sandy oolites of the Ajalon Series, the youngest Dogger of the area, strongly suggest the relics of a channel which meandered across the almost filled embayment where ooliths, shell debris, and ill-graded sand finally accumulated, derived from the south and south-west, as is indicated by current-bedding. Only at Yew Grain did the Ajalon rocks suffer subsequent and local alteration to Black Oolite, though deltaic distributary channels of the succeeding Lower Estuarine Series cut deep into the Dogger in several localities.

SUMMARY

1. A sequence of strata is determined in the Dogger of Upper Eskdale and its tributary valleys. The rocks fall into three main series, which are subdivided into groups.

2. The underlying Yeovilian sediments, originally included with the Dogger, are mapped and briefly described. The unconformity between them and the Dogger is emphasized.

3. The Dogger is marine throughout but only the oldest yields an adequate faunal assemblage, similar to that of the Glaisdale Oolite Series (upper *opalinum*). The greater part of the Dogger of this area is therefore younger than that of the Yorkshire Coast.

4. Chemical changes in the sea-water caused the deposition of siderite to characterize the earliest phase (Glaisdale Oolite Series). This was succeeded by a phase of dominantly chamosite deposition (the Chamositic Series) followed by a reversion to siderite deposition (the Ajalon Series).

5. Earth-movement controlled sedimentation over the area. During the first phase an eastern tilt to the region held the centre and west above or near sea-level, where it received no sediment. The second phase saw general depression with the accumulation of shallow water sediments. This was followed by uplift and erosion when a broad shallow valley was cut. Partial depression then flooded the valley with derived marine sediments.

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Notes on *Actinocrinites elephantinus* Austin and *Amphoracrinus brevicalix* Rofe

By James Wright

(PLATE VIII)

1. *Actinocrinites elephantinus* Austin

BEFORE the Austins published their *Monograph on Recent and Fossil Crinoidea*, they issued to prospective subscribers an illustrated circular intimating the forthcoming publication of the work. Through the kindness of Professor W. T. Gordon, of King's College, London, I have a copy of this circular. It is in one sheet, printed on one side only and measures 7¼ in. by 9½ in. Over one-third of the upper part of the printed page is occupied by two specimen illustrations, "*Platycrinites laevis* (Miller)" on the left, and "*Actinocrinites elephantinus* (Austin)" on the right hand side. The genus *Platycrinites* was later fully described in parts 1, 2, and 3 of the Monograph, and a facsimile of the drawing of *P. laevis* of the circular is given on pl. i, fig. 1*e* of the Monograph. The illustration of *Actinocrinites elephantinus* Austin, however, does not seem to have been published in any work by the Austins prior or subsequent to part 8 of the Monograph, which was the last number to appear. The genus *Actinocrinites* was not dealt with in the parts then issued, but it seems certain that it would have been had the remaining numbers been published. Since the present year (1943) marks the centenary of the publication of parts 1 and 2 of the Monograph, I have thought it of some interest to give a copy of this drawing of *A. elephantinus* as it appears on the circular (Plate VIII, Fig. 1). The Austins' specimen probably came from Hook Head, Ireland, and for comparison with it three specimens from this locality in my own collection are given on the same plate, figs. 2, 3, and 4. Before referring to them again some further details regarding the circular and the publication of the Austins' Monograph may be of interest. The circular is dated 15th May, 1842. Below the two illustrations already mentioned is the heading "A Monograph on Fossil Crinoidea" followed by the words "in which many new and important Genera and Species will be for the first time figured and described and their Geological range and distribution defined. To which will be added Figures and descriptions of some recent fossil allied Genera By Thos. Austin Esq. and Thos. Austin Junr. Civil and Mining Engineer". The circular then goes on to state the object and scope of the Monograph and continues, "From the very great expense attendant on getting out a work containing such highly finished illustrations as the Monograph will possess it is proposed to publish it by subscription." It further continues with the following words which were reprinted with little change on the covers of the different parts as they appeared, "The Work will be published in Royal Quarto in Numbers at 3*s.* 6*d.* each. Every No. will contain two Lithographic plates of several figures with a proportion of letter press. A few Copies only will be carefully coloured at 5*s.* each. About 20 Nos. will complete the work." The authors' address is given at the foot of the circular, "No. 1 Paul St., Kingsdown, Bristol" and the imprint " Lavars & Ackland, Lithog. Bristol " at the right hand bottom corner. I have not seen any of the coloured copies mentioned above, but I am fortunate to possess the late Dr. F. A. Bather's copy of the eight uncoloured numbers as published and bound in one volume. This I owe to Mr. Andrew Templeman of H.M. Geological Survey who was so generous as to present me with the copy. Inserted in the book is a copy of a letter sent by Dr. Bather to a correspondent giving details of the dates of publication of the Monograph. Since these details differ in some respects from those given by Bather in *Ann. Mag. Nat. Hist.*, 1890, p. 308, and do not seem to have appeared elsewhere I quote the letter in full here. It is dated 2nd May, 1903, and is copy of a reply to Mr. F. B. Weeks, Washington. It reads, " Mr. C. Davies Sherborn has handed to me your letter of 11 April inquiring as to the dates of the various parts of the 'Monograph on Recent and Fossil Crinoids' by T. and T. Austin. In April 1890 I published in the *Annals of Natural History* the result of my researches on this subject up to that time. I have since been able to make one or two corrections and confirmations and the following statement is, I believe, as correct a one as you are likely to obtain :—

No. 1. Sig. B, C. Pp. 1–16, Pls. I, II and frontispiece. 1843, April (date on wrapper).
No. 2. Sig. D, E. Pp. 17–32, Pls. III, IV, 1843, June or later (date on Plates).
No. 3. Sig. F, G. Pp. 33–48, Pl. V, VI, 1844 (T. Austin, senr. adds F.G.S. on wrapper, elected January, 1844).
No. 4. Sig. H, I. Pp. 49–64, Pls. VII, VIII, 1845 (Pl. VIII bears date 1844).
No. 5. Sig. J, K. Pp. 65–80, Pl. IX, X, 1846. (This date is confirmed by Austin's MS.).
No. 6. Sig. L, M. Pp. 81–96, Pl. XI, XII, 1847 (Pl. XI bears date September, 1846).
No. 7. Sig. N, O. Pp. 97–112, Pls. XIII, XIV, 1847.
No. 8. Sig. P, Q. Pp. 113–128, Pls. XV, XVI, 1847 (authority *Q.J.G.S.*, xxxviii, Proc. p. 53)."

After the publication of No. 8 the project of carrying on the Monograph seems to have been abandoned, probably for lack of funds, and many of the Austins' species were left unfigured. So far as these notes are concerned this applies specially to the species of *Actinocrinites*, seven of which were described without figures in *Ann. Mag. Nat. Hist.* 1843, pp. 200–201. These species are as follows :—

1. *Actinocrinites elephantinus* Austin
2. " *cataphractus* Austin
3. " *aculeatus* Austin
4. " *crassus* Austin
5. " *granulatus* Austin
6. , *laevissimus* Austin
7. " *longispinosus* Austin

In 1848, the Austins proposed the new genus *Amphoracrinus* and included in it two species from the above list, viz. *A. crassus* and *A. granulatus*. From the descriptions given in 1843 it appears that the remaining five species, with perhaps the exception of *A. laevissimus*, are characterized by the possession of a fairly long anal tube. One gathers that the tube is longest in *A. elephantinus* and in " some specimens exceeds two inches in length ". The special interest of the drawing of the circular of *A. elephantinus* here given (Plate VIII, fig. 1) is that it is apparently the only figured species in the above list now to appear in print. It also shows the anal tube in good detail. This structure is rarely preserved in English specimens of *Actinocrinites*, the majority of which consist of calices or thecae only. On the other hand, while many of the Hook Head specimens have the tube intact and well preserved the cup and tegmen are often in great part embedded in the matrix or wanting and so the specimens are very difficult to determine. With the possible exception of the two specimens assigned to *Amphoracrinus* most if not all of the Austins' species in the above list probably came from Hook Head. In my own collection are four specimens from this locality which show the anal tube fairly well. The three illustrated on plate VIII figs. 2, 3, and 4, give a good idea of the state of preservation of the Hook Head material. To determine such specimens from the short descriptions of the Austins is not easy and indeed cannot be done satisfactorily without an examination of the Austins' types and a large series of specimens from the same locality. So far as can at present be judged, our fig. 3 is perhaps the only specimen which with any confidence can be referred to *A. elephantinus*. The anal tube in this species is stated by the Austins to have plates with " an elevated ridge in the centre of each ". Our specimen is smaller than the Austins' figure and is much weathered, but a few of the better preserved plates of the tube are of this nature. It is not likely to be *A. cataphractus* where the tube " is covered from its base to its apex with a set of abruptly conical plates arranged spirally ". Our fig. 2 does not conform to the descriptions of the two species mentioned. In this specimen the cup is not well preserved, and although the anal tube is well shown, the plates are rather worn. They are, however, strongly spiniferous throughout as are also the plates of the tegmen at the base of the tube. The species is more likely to be *A. aculeatus* or *A. longispinosus*. The Austins state that *A. aculeatus* has a tube " elongated and covered with minute plates, most of which are furnished with a thorn-like projection in their centres ". In *A. longispinosus*, the tube is said to be " long and covered with minute plates " but no mention is made of spines on the tube, although the tegminal plates are " elongated into spines of very great length ". No tube is mentioned in the description of *A. laevissimus*. In our fig. 4 the anal tube is long and composed of plates which are quite smooth without ornament. They are not worn. This specimen is extremely interesting in that it shows a continuous row of arms and arm bases round the calyx, a feature which indicates the genus *Cactocrinus*. It raises the question as to whether all five of the Austins' species really belong to *Actinocrinites*. The drawing of *A. elephantinus* (Plate VIII fig. 1), does not show the arm connections very clearly, although part of the cup is preserved. Our Plate VIII, fig. 4, however, is definitely a species of *Cactocrinus* and illustrates the occurrence of this genus among the Hook Head crinoids. Dr. Bather has remarked somewhere, either in a personal letter or in some paper, about the presence of *Cactocrinus* among the Austins' crinoids, but I cannot find the reference at present. Wachmuth and Springer (1897, p. 600) also state that *Cactocrinus* " may possibly be represented in Europe in the Mountain Limestone of Ireland, but, so far as we know, not in the Yorkshire beds of England ". It is perhaps of interest to add that in an examination of some hundreds of Actinocrinitids from the Clitheroe area not one so far has been found which belongs to *Cactocrinus*. It is hoped to deal with some of these Clitheroe forms later. In these notes the names *Actinocrinites* and *Platycrinites* are given in their original spelling. *Actinocrinus* and *Platycrinus* are synonyms (Bassler, 1938, Moore and Laudon, 1943).

2. *Amphoracrinus brevicalix* Rofe

When studying the Clitheroe specimens referred to *Pimlicocrinus* and *Amphoracrinus* (Wright, 1942, 1943), a short paper by Rofe was unfortunately overlooked (Rofe, 1865, pp. 12–13). This paper is illustrated by three text-figures and describes the new species *Actinocrinus* (*Amphoracrinus*) *brevicalix* Among the characters of this species are the low cup (to which it owes its name) and the high tegmen. Rofe's specimen comes from the Clitheroe area and is stated to be in the British Museum. The outline of the specimen itself as given by Rofe in his fig. 1 is not unlike that of *Pimlicocrinus clitheroensis*, except perhaps that the cup is deeper and more rounded than in our species, with less overhang of the brachial lobes. His fig. 2 shows the base in its general characters, especially as to the incorporation of the first tertibrachs in the cup, to be remarkably like that of *P. clitheroensis*. In fact at a first glance at this figure it seemed that Rofe's species might be identical with our Clitheroe form. Closer examination, however, of figs. 1 and 3 discloses that in *A. brevicalix* there are certain other characters which, if correctly interpreted by Rofe in his figures and description, prove it to be unique and quite distinct from *P. clitheroensis*. Chief among these are the long narrow tapering interbrachials and the long narrow plates of the lower part of the tegmen. The diagram of the cup of *A. brevicalix* given by Rofe (fig. 3) shows that in the posterior interradius X is surmounted by three plates, not two as in *P. clitheroensis*, and on top of these is a long narrow tapering plate of peculiar character which extends upwards between the arm bases for some distance into the tegmen. In each of the other four interradii the first interbrachial is succeeded by two plates as in *P. clitheroensis*, but unlike the latter species these are followed by a long single narrow tapering plate of the same character as that which occurs in the posterior interradius. In *P. clitheroensis* the two plates above the anal X are followed in the holotype (No. 2382) by two ranges of three plates of normal size and character which fill up the space between the arm bases and meet the tegminal plates above. In the other four interradii the first interbrachial is succeeded by two plates, somewhat longer than the first interbrachial, and these also extend up between the arms bases to meet the tegmen. Although noticeably longer the second row of interbrachials are not markedly different from the lower plates of the tegmen. In the small paratypes (Nos. 2393, 2394) there are slight modifications from this, but the plan is essentially the same. (These specimens represent young individuals. The posterior interradius is narrow here and there is only room for two interbrachial plates between the right and left posterior lobes instead of the double range of three plates in the large holotype.) Rofe's figures show that the long single narrow tapering interbrachial plates in *A. brevicalix* not only fill in the space between the arm bases in all five interradii, but extend upwards and form part of the lower portion of the tegmen. Of this part of the tegmen Rofe says, " The plates of the first row above the arms are much longer than wide and given an appearance very different from that of any other published figure of this genus found in the Mountain limestone." This tegminal feature is quite different from that of *P. clitheroensis* where the first row of plates above the arms are of normal proportion and character compared with the higher plates of the tegmen (Wright, 1942, pl. x, figs. 1–4, 1943, pl. iii, figs. 18, 19). Rofe refers his species to *Amphoracrinus* and states that the tegminal plates above the row of long narrow plates " are smaller, and of various shapes, except the summit plates which are similar in their proportion and arrangement to those usual in *Amphoracrinus*—that is one large plate at the summit surrounded by six other plates and the ' proboscis ' ". Since the anal tube is broken away and the top of specimen defective perhaps the anal opening was more central than in *Amphoracrinus* and not unlike that of *P. clitheroensis*. The side view (fig. 1) is suggestive in this respect. The curious and distinctive features of *A. brevicalix*, however, are the long narrow plates in the tegmen above the fixed brachials together with the long single narrow tapering interbrachials in all five interradii. Such features mark *A. brevicalix* sharply off from *P. clitheroensis*. Whether Rofe's species should be referred to *Pimlicocrinus* cannot at present be decided. One would like to see the specimen itself and make certain that the long narrow plates of both tegmen and interradii are correctly figured. Rofe's side view (fig. 1) is not too clear. Rofe, however, was an acute observer and for the present we must accept his conclusions.

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EXPLANATION OF PLATE

FIG. 1.—Copy of the illustration of *Actinocrinites elephantinus* Austin which appeared on the circular issued by the Austins in 1842.

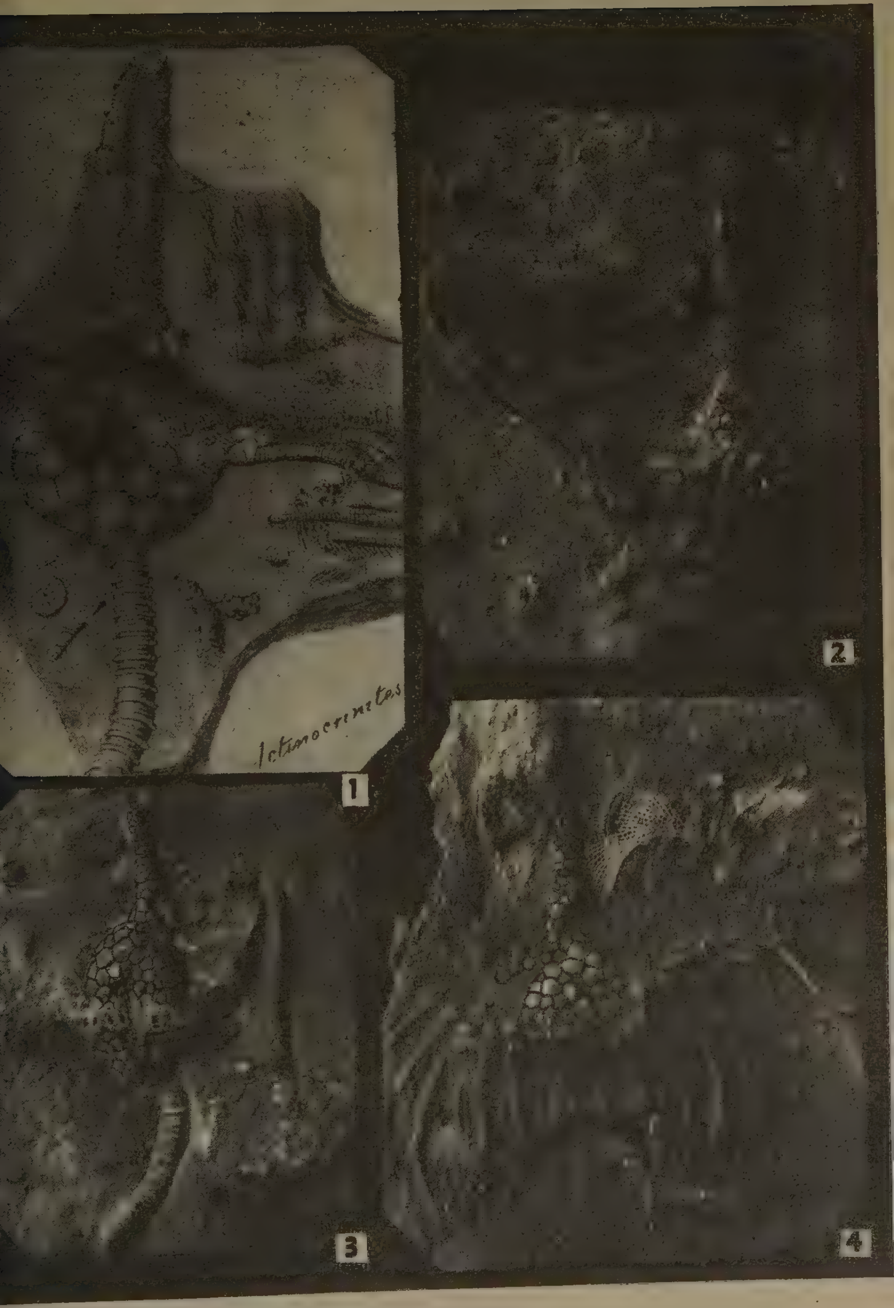
FIG. 2.—Specimen with a long spiniferous anal tube probably belonging to *Actinocrinites aculeatus* Austin or *A. longispinosus* Austin. On the left

of the tube, near the middle, are the remains of a blastoid with brachioles in position. Another blastoid lies near the left top corner of photograph and another two blastoids near the left bottom corner. J.W. Coll. No. 2436.

FIG. 3.—Specimen provisionally referred to *Actinocrinites elephantinus* Austin. The calyx and tube here are considerably weathered as is also the tube of another specimen seen on the right. The cup of the latter is buried in the hard matrix. J.W. Coll., No. 2437.

FIG. 4.—This specimen represents the genus *Cactocrinus* and possibly belongs to an undescribed species. Note the continuous row of arm bases and arms across the calyx at the base of tegmen. Below the arm bases the cup is much obscured. J.W. Coll., No. 2435.

The three specimens figured on this Plate are from Hook Head, Ireland. The Austins' specimen of *A. elephantinus* probably also came from this locality. All photographs natural size.



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ACTINOCRINITES ELEPHANTINUS AUSTIN AND *CACTOCRINUS* SP. FROM HOOK HEAD, IRELAND.

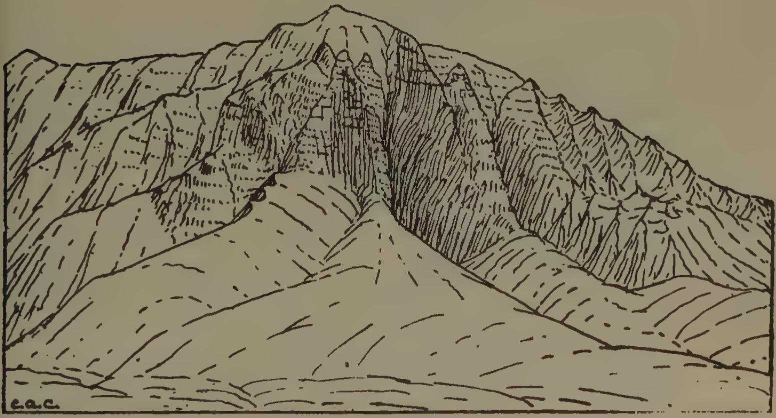
Oahu Valley Sculpture: A Composite Review

By C. A. Cotton

INTRODUCTION

SOME remarks recently made by Dr. Rastall in the *Geological Magazine* have drawn attention to a present need for objective study of valley sculpture in tropical rain-forest regions. Pending the collection of further data in difficult terrains like the Malay Peninsula and the Owen Stanley Range of New Guinea we have available some well-reasoned theories that have been offered in explanation of the peculiar forms assumed by most Hawaiian valleys—forms that are perhaps peculiar only when judged by cool-temperate standards.

It is true that these valleys are confined to a basaltic terrain and that the valleys have all originated on the slopes of domes. Valleys of this "Oahu" type are developed typically, however, on hot, wet windward slopes, and it may well be inferred, or at least strongly suspected, that theories of valley sculpture here developed will be broadly applicable to the majority of rain-soaked hot regions with strong relief. Though it has been shown that structure exercises some control of slow valley-development even where outcrops are thickly covered with soil in a district with little available relief,[1] the processes involved in deep tropical dissection are very different. Provided that chemical weathering penetrates deeply and proceeds rapidly enough to keep ahead of denudation, the



TEXT-FIG. 1.—Fluted side wall of U-shaped valley of the Oahu type, Kolalau Valley, north-western Kauai, Hawaiian Islands. (From a photograph.)

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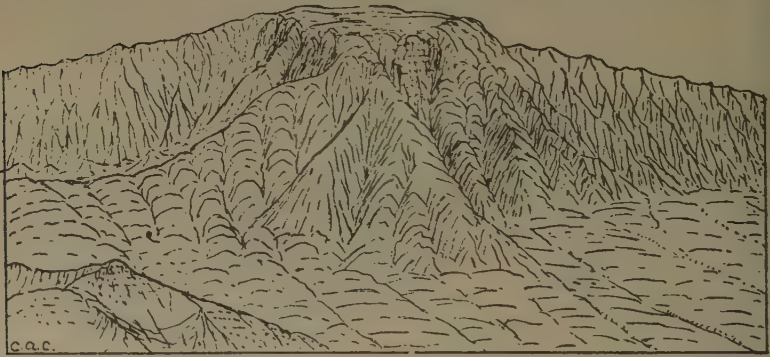
[1] P. E. Wolfe, Soil and Subsequent Topography, *Jour. Geol.*, 51, pp. 204–211, 1943.

nature of the bedrock may have little influence on the development of surface form.

A reliable informant has impressed upon me the influence of deep weathering on sculpture in the Malay Peninsula.[1] In such places strike-controlled structural ridges, which are familiar forms in the cool belts, are rarely seen, for tropical weathering is no respecter of rock types. With the exception perhaps of the hardest quartzite strata the formations are rotted by weathering and come to exhibit a sameness of dissection forms as the products of chemical decay are carried down their slopes by mass transportation. Few explicit statements have been made as to the prevalence (or otherwise) of adjustment to structure in the regions of tropical jungle and rain forest. It may be suspected, however, that adjustment is generally very imperfect.



TEXT-FIG. 2.—A small plateau remnant of the constructional basalt-dome surface isolated at a point where amphitheatre-shaped valleys almos intersect, Mount Kaala, the highest point on Oahu, Hawaiian Islands (From a photograph.)

Even in the cooler belts (but outside regions stripped of soil by glaciation "earthflow" is the dominant process of denudation in some terrains.[2] In the rain-soaked tropics it assumes almost a universal rôle.

DISSECTION OF BASALT DOMES

Basalt domes (shield volcanoes of the Hawaiian type) are dissected b valleys, chiefly consequent, that are generally steep-sided and have cirque-like amphitheatre heads.[3] Besides valleys of the kind normally founc entrenching themselves in lava plateaux, especially in cool and comparatively dry climates, there are others of a distinct type. The forme separate mesas, planezes, and ridges bounded by escarpments whicl present no unusual features; residual peaks are commonly of stepped-pyramid form and the valleys are bordered in parts by structural terraces. Other valleys, however, are more distinctly U-shaped in transverse profile, with broad floors, steep side walls which are not stepped but vertically fluted (Text-fig. 1), and very conspicuously amphitheatre-shaped heads (Text-fig. 2). These valleys separate ridges with intercatenary profiles (Text-fig. 3), like those of ridges between closely spaced glacial troughs, and from these ridges isolated pinnacles like Alpine horns may rise. Such valleys, which are common in the Hawaiian Islands, may be classed as the Oahu type. In the islands of Kauai, Molokai, and Maui they are youthful and are still in the process of rapid development and headward extension, but in Oahu they have reached full maturity and even old age.

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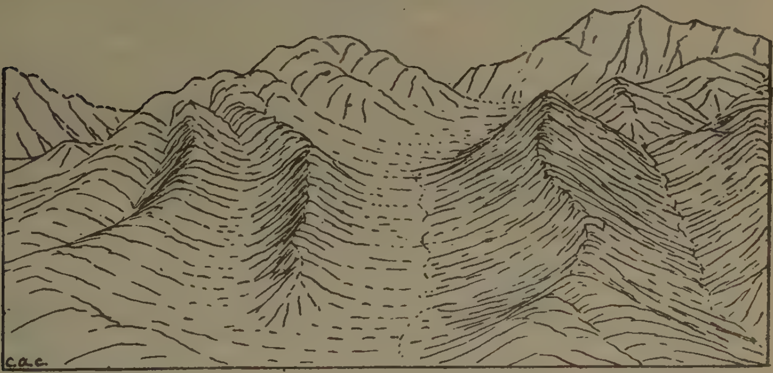
[1] J. A. Richardson, orally.

[2] C. F. S. Sharpe and E. F. Dosch, Relations of Soil-creep to Earthflov in the Appalachian Plateaus, *Jour. Geomorph.*, 5, pp. 312–324, 1942.

[3] N. E. A. Hinds, Amphitheatre Valley Heads, *Jour. Geol.*, 33, pp. 816–18 1925.



TEXT-FIG. 3.—The U-shaped Nuuanu Valley and intercatenary ridges at Honolulu, Oahu, Hawaiian Islands. (From a photograph.)

ORIGIN AND DEVELOPMENT OF OAHU VALLEYS

The radial pattern of well-developed Oahu valleys indicates that they are consequents. For this and other reasons they seem to be entirely different in origin from the somewhat similar amphitheatre-headed (but spring-guided and insequent) "alcoves" tributary to the Snake River in Idaho,[1] which are also in a basalt terrain.

It appears rather that autogenetic falls have developed at an early stage of the dissection of the dome and that retreat of these at the head of a newly opened inner valley has proceeded as a kind of autogenetic rejuvenation which might almost be thought of as fluvial "over-deepening". This has been accompanied by lateral enlargement of the inner valley to a broadly U-shaped or catenary trough by a wall retreat in which special processes have been active. The steep side and head walls of the troughs are fluted in a pattern of close-set spurs and ravines, or chutes, which are so precipitous in some cases as to merit the description " vertical valleys " sometimes applied to them ; and it is clear that this pattern is a by-product of the processes that are enlarging the trough both sideward and headward.

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[1] H. T. Stearns, Origin of the Large Springs and their Alcoves along the Snake River in Southern Idaho, *Jour. Geol.*, 44, pp. 429–450, 1936.

As explained by Palmer[1] some of the flutings are solution forms, or lapiés, though on an enormous scale. According to Palmer : " The flutings at Waimalolo [in Oahu] extend vertically 1,600 or 1,700 feet . . . from the top of cliffs . . . down to the tops of alluvial slopes. . . . The small but persistent run-off . . . supplies a gentle, steady flow of water. . . . The water cannot break away, it cannot fall freely and develop a high velocity, and it is therefore not a strong agent of mechanical erosion. The work of erosion must be done chiefly by solution."

Giant lapiés are rather exceptional forms, being limited in their occurrence to near-vertical valley walls, which are possible only where the rocks are not very deeply rotted by chemical weathering. A somewhat similar pattern of flutings on the upper side-walls of many Oahu valleys, which, however, ascend at an inclination rarely much steeper than 45°, is attributed by Wentworth[2] to erosion effected by a process of shallow landsliding which from time to time (during very heavy rains) cleans out each gully, or chute, by removing the soil, a foot or two in depth, together with its clothing of forest vegetation, as a " soil avalanche ". As the whole of the upper valley-side thus affected is forest-clad, soil is held by the mat of roots on very steep slopes, and the fluted slope is maintained at an angle of about 45° during gradual retreat. (Slopes rather steeper than the average are found at the heads of chutes, however.) Chemical weathering develops new soil on scars which have been bared by landsliding, and they are colonized by vegetation, which holds the accumulating soil in place until the cycle is repeated by the occurrence of another slide. The sharpened spurs between the deepened chutes are progressively reduced in height by the same process, and the whole valley-side slope retreats horizontally without appreciable change of form.

Oahu valleys are developed typically only under an extremely heavy rainfall ; and rapid tropical weathering is also essential. These are the conditions under which generally concave valley-side slopes and knife-edge divides become the rule on almost every kind of terrain.

According to Stearns,[3] the gathering in of headwater tributaries by abstraction in the course of an early struggle for existence among approximately parallel consequent streams on a rain-soaked surface of considerable slope (the flank of a dome) prepares a master stream emerging from the struggle to take up the task of excavating a steep-headed trough (Text-fig. 4, A). A rough analogy may be traced between such a valley-head and a trough-end in a glaciated valley, which has resulted from glacial over-deepening below the confluence of a group of convergent valley-head cirques.

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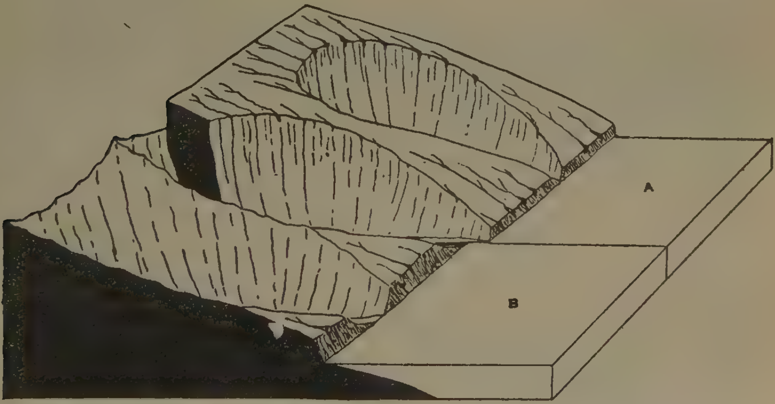
[1] H. S. Palmer, Lapiés in Hawaiian Basalts, *Geog. Rev.*, 17, pp. 627–631, 1927.

[2] C. K. Wentworth, Soil Avalanches on Oahu, Hawaii, *Bull. Geol. Soc. Am.*, 53, pp. 53–64, 1943.

[3] H. T. Stearns, Geology and Ground-water Resources of the Island of Oahu, Hawaii, *T.H. Div. Hydrog. Bull.*, 1, pp. 24–6, 1935.

The next stage is characterized by the processes of slope (or wall) retreat already referred to, which enlarge the " rejuvenated " or " over-deepened " part of the valley (now a trough) and extend it headward (Text-fig. 4). It is at this stage that the troughs are widened by the " soil-avalanching " process, as described by Wentworth. According to Stearns, rapid extension of the trough headward takes place by vigorous plunge-pool erosion. This process can continue as long as the tributaries collected by abstraction still pour into the head of the trough ; but it is generally replaced by giant-lapiés erosion or some form of slow slope-retreat when the trough head has been sapped back to a sharpened divide, unless, as is sometimes the case, there is still available a supply of perched or high-level ground water which continues to issue from springs in the valley head, as Stearns has found to be the case along the migrating asymmetrical divide which forms the Pali (inland line of cliffs) of Oahu.[1]



TEXT-FIG. 4.—Two stages in the development of valleys of the Oahu type on the slope of a dome. (Redrawn after diagrams by Stearns.)

While there is still a gathering ground for surface streams which continue to enter the trough at its head these will continue to erode and descend by " vertical valleys ", or chutes, which flute the head-wall.[2] These flutings are not strictly giant lapiés such as have been described by Palmer, but somewhat resemble them. The true giant lapiés are found only at the stage at which trough heads intersect in very steep-sided knife-edge ridges or arêtes.

The process of headward extension of the inner trough has been described by Stearns as follows :—

" Captured tributaries entering a master stream form a rim of coalescing plunge pools about the amphitheatre wall at the break in the stream gradient. The narrow ridges between the pool are undercut and fail by their own weight."

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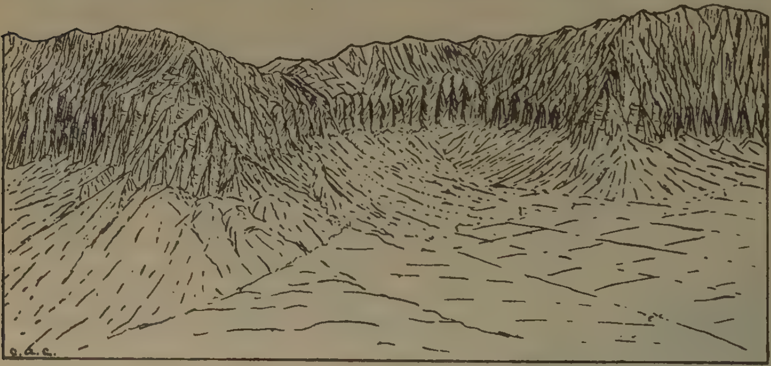
[1] Loc. cit. (8), p. 28.

[2] As an example of a valley at this stage the trough entered at its head by Halawa Falls, on the island of Molokai, is cited. See C. A. Cotton, *Landscape*, Plate IX (2), 1941.

It must be remembered that the material which is thus collapsing, like that beside it which is in course of excavation by plunge-pool erosion, is basalt that has long been above the water table and is thus much weakened by chemical decay. Stearns has pointed out that the ground-water level in Oahu (except in certain districts where ground water is held up at higher levels by dykes) is far below most valley floors, being indeed but little above sea-level and ascending inland at a gradient of no more than 3 feet per mile, whereas the valley floors ascend at 40 or more feet per mile.[1]

In some valleys of the Oahu type there are perennial streams which are fed in part by ground water locally held up at high levels by dykes, and also by springs issuing from bodies of perched water, as well as by the run-off from rain-soaked uplands. Such streams are vigorous enough to transport much gravel and thus to dispose of the debris of rock falls and landslides, especially that constantly supplied at the head of a rapidly-developing trough. Many valleys on the island of Oahu, however, are heavily encumbered with talus, which has accumulated as a thick apron along each trough side. This accumulation has been attributed by Stearns to a relict condition due to a shrinkage of rainfall which has followed as a consequence of erosional reduction of relief and which has made the streams in the troughs underfit. The talus is very thoroughly decayed by chemical weathering, and it may be that removal of such material in valleys, the floors of which are above the level of ground water, takes place mainly in solution.



TEXT-FIG. 5.—Coalescing valley heads make a scalloped cliff (the Pali) at the rear of the planed lowland of north-eastern Oahu, the re-entrant at the head of Haiku Valley, west of Kaneohe. The cliff is sculptured in detail by " vertical valleys ". (From a photograph.)

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[1] Loc. cit. (9), p. 24.

REDUCTION TO A PENEPLAIN

A continuation of the process of wall retreat not only sharpens the intercatenary ridges between Oahu valleys (Text-fig. 4, B), but eventually destroys them. Peneplanation by some such process has eliminated a former strong relief along the north-eastern seaboard (the windward and therefore the wettest and most rapidly eroded slope) of Oahu. Here (Text-fig. 5) the valley heads, still extremely steep and now coalescing owing to destruction of the ridges which formerly separated the lower valleys, make the continuous and very imposing cliff known as the Pali, which some observers have interpreted as a fault scarp. The crestline of this " pali " forms a divide which is still migrating and consuming the dissected remnant of a dome.

REVIEWS

THE GEOLOGY OF THE WEST COAST FROM ABUT HEAD TO MILFORD SOUND : Part 1. By H. W. WELLMAN and R. W. WILLETT. *Transactions and Proceedings of the Royal Society of New Zealand*, vol. 71, pp. 282–306, 1942. Part 2, Glaciation. Ibid., vol. 72, pp. 199–219, 1942.

Nine pages of Part 1 are devoted to " Physiography " and three to " Geological History ". The authors amplify evidence of the existence of a widely developed peneplain of late Tertiary age in south-western New Zealand and over the Southern Alps. " It is likely that the [Southern] Alps were reduced to low relief not only during the deposition of the Tertiary beds . . . but also later by the formation of the late Tertiary peneplain after they had been re-elevated during the folding of the Tertiary sediments." Their observations support the view of Benson that Fiordland has escaped the strong deformation in very late Tertiary or post-Tertiary times to which abundant features of tectonic origin in most other parts of the New Zealand region must be ascribed. Orogenic deformation of the south-western district, accompanied by folding of Tertiary strata and their involvement with older rocks in overthrust structures, took place at an earlier date, however, and was followed by prolonged erosion during which the " late Tertiary " peneplain was developed. The authors ascribe to the peneplain a definitely later date than that (" Miocene ") tentatively adopted for it by Benson. " If the folding of the Tertiary beds is post-Waitotaran, then this surface must have been formed in Nukumaruan or Castlecliffian [late Pliocene] time."

The " late Tertiary " peneplain not only survives in summits and rather obviously accordant summit levels which have been noted by various observers in Fiordland, but a restoration of it from summit levels is now mapped (Fig. 4) in contours at 1,000-ft. intervals over the highest part of the Southern Alps. According to this interpretation uplift of the surface has been accompanied there by broad warping without any strong deformation, and drainage lines in the region described are explained as for the most part consequent on the arched form. "This hypothesis involves elevation of about 10,000 feet along the Alpine axis in late Tertiary time. The consequent stream system flowed north-westward across the grain of the country, and was probably quickly modified by subsequent streams." Consequent relationship of drainage lines south-east of the crest-line of the Southern Alps in the Mount Cook area to the same up-arched peneplain is also suggested. "There was little relief to interfere with the direct course of the rivers." Here it may be remarked that a similar suggestion was made by Speight in 1911.

The conclusion is reached that in the Southern Alps repeated uplifts have taken place at long intervals on essentially similar lines ; for the trend lines of Mesozoic and Tertiary folding remain parallel to the major tectonic features of later origin.

The authors trace also the course of the "Alpine Fault", which has been recognized as the north-western boundary of the Southern Alps uplift. The mountains do not descend to the Tasman Sea. "Although the Alps are only from 20 to 30 miles from the sea they do not slope evenly towards it. . . . No extensive areas of high land comparable to the Alps occur on the north-west of this fault, and the mountains, which rarely rise above 2,000 feet, are separated by wide areas of low relief." The fault has probably persisted, or has occasionally reappeared as a major landscape feature as a result of intermittent renewals of differential movement since the Southern Alps first arose as a positive crustal element in the late Mesozoic.

No young fault scarp has been described as in existence at present along this line ; but it is recognized in various parts of its length by : "(1) The presence of a scarp or a sudden but regular change in summit height ; (2) wide crush zones with slips and rapid erosion ; (3) subsequent rivers flowing along co-linear courses parallel to the trend of the Alps, connected by low passes ; (4) changes in rock type ; (5) offsetting of river courses." By such means the fault has been traced for a great part of the length of the South Island, and it is found to be "the same as that which forms the even Fiordland coast from Milford Sound to Breaksea Sound".

"For the whole of the 400 miles over which the fault has been mapped . . . it shows no minor irregularities, being a curve convex to the west at the southern end . . . becoming practically a straight line from Milford Sound to Grey River. . . . Its regularity and association with the main axis of the South Island suggest that it has played an important part in the formation of the Southern Alps."

Part 2 is a contribution quite distinct from the first, dealing exclusively with glaciation and almost exclusively with morainic deposits. The authors support and amplify the conclusions of Julius von Haast (*Geology of Canterbury and Westland*, 1879) as to the enormous extent and thickness of the moraines at the western foot of the Southern Alps—a vastly greater accumulation than any other of the same kind (above sea-level) in the New Zealand region.

The glaciation of the Southern Alps is not discussed fully, but attention is confined to the strip of land (with an average width of about 10 miles) between the mountains and the Tasman Sea. In the belt dealt with there are in addition to the morainic forms some knobs of granite and gneiss with relief in some cases of over 2,000 feet. These knobs when they were over-ridden by a piedmont glacier had already become " isolated from one another " as a result of differential erosion which had reduced intervening greywackes to lower relief.

The surface of the morainic belt descends seaward with an average slope of 2° to 5° from 1,500–2,000 feet at the base of the mountains to 100–400 feet at the western shoreline, where it ends in bluffs that have been trimmed back by marine erosion. From a distance the moraines give the impression of a rather smooth seaward-sloping bench, but this is illusory. The long interfluvial ridges of moraine, though fairly accordant in summit levels, are not generally flat-topped. Moreover, " the layers of material that form the moraine are generally sub-parallel to the surface of the moraine."

Not only does this structure indicate the constructional character of the landforms, but itself calls for explanation. " The deposition of sub-parallel layers of moraine upon an irregular surface by successive ice advances is regarded as a reasonable explanation." It is somewhat disappointing, in view of the reference to successive ice advances, to find that the authors have apparently not yet been able to differentiate and correlate deposits of successive glaciations in such a way as to distinguish separate glacial epochs.

The authors suggest 3,000 feet as a minimum for the elevation of the surface of the " ice sheet " (or piedmont glacier) in the vicinity of the " Alpine " fault, which is approximately the inland boundary of the belt of abundant deposition.

The morainic landscape is found to resemble that farther to the south along this coast, which other observers have regarded as merely a morainic veneer over an eroded bench, and the authors favour the view that thick morainic deposits such as they find in this district are present also far to the south. " Similar seaward-sloping landforms constitute a conspicuous feature of the West Coast from Ross southwards to Bruce Bay, from the Cascade Plateau to Milford Sound, and in Fiordland south from Resolution Island."

The absence of fiords in the moraine-covered coastal district north of Fiordland, of which J. W. Gregory made some capital in *The Nature and Origin of Fiords*, finds a satisfactory explanation, for " the chief difference between the Southland fiords and the glaciated South Westland valleys is the amount of post-glacial debris that has accumulated in them ". A restoration of the shoreline which resulted from withdrawal of the ice of the Glacial Period shows as fiords a number of very deep valleys which are now filled with alluvium.

A remarkable change in the character of the morainic debris from greywacke in lower layers to schist above is found in that part of the district in which the " Alpine " fault separates rocks of these types in the underlying terrain. It may be explained as a result of renewed movement on this fault. " Over the fault scarp thus formed the glaciers plunged as ice-falls till erosion along the schist belt re-established the grade. . . ."

A contemporaneous marine facies of fossiliferous and varved silts is found interbedded with the moraines.

C. A. C.

THE CRETACEOUS ROCKS OF SOUTH INDIA. By L. RAMA RAO. *Lucknow University Studies*, No. XVII, pp. iv + 78, with 4 maps, 1942.

This small book is founded on two lectures given at the University of Lucknow in 1940. It deals only with the Cretaceous rocks of the region about Trichinopoly and Pondicherry, which were laid down during the transgression of a southern and eastern sea apparently distinct from Tethys. The range is from Cenomanian to Danian. One of the points brought out is that the evidence supports the idea that the " Cenomanian " transgression here actually began well down in the Albian. The rocks are highly fossiliferous, with a good development of limestones and some enormous ammonites, which are not named. Certain beds of flint and chert are shown to be silicified limestones, some being practically quartzites. The highest beds of all belong to the uppermost Cretaceous or possibly even form a transition to the Eocene, and this fact is of special interest, since in one place they are overlain by a small outlier of the Deccan Traps, suggesting that these are probably in part at least Tertiary. No reason has been found to modify the original classification by H. F. Blanford in 1862 into Utatur, Trichinopoly, and Ariyalur series, except that the author now separates the original Upper Ariyalurs as the Niniyur Series, as this may belong to a separate transgression.

R. H. R.

ANNOUNCEMENT

CLOUGH MEMORIAL RESEARCH FUND

This fund was instituted in 1935 for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Cumberland, Durham, Westmorland, and Yorkshire. Under the terms of the administration of the fund a sum of approximately £30 is available annually.

Applications for grants for the period 1st April, 1944, to March, 1945, are invited. Applications should state :—

1. The nature of research to be undertaken.
2. The amount of grant desired.
3. The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavation of critical sections, etc.
4. Whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Research Fund Committee, Edinburgh Geological Society, Synod Hall, Edinburgh, not later than 1st March, 1944.

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